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THE FEDERAL AVIATION ADMINISTRATION LIGHTNING PROTECTION MODULE--ETC(U)
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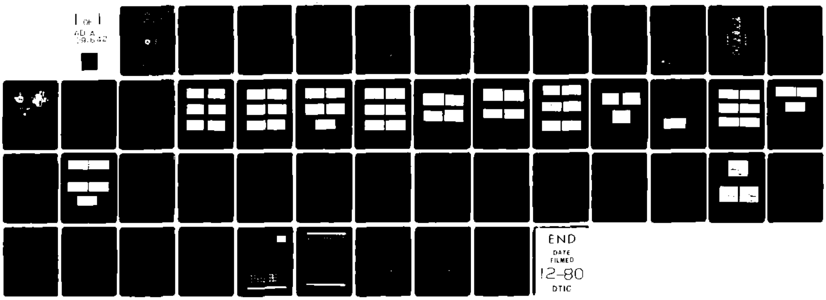
UNCLASSIFIED FAA-RD-80-119 NL



Report No. FAA-RD-80-119

LEVEL II

(12)

AD A091642

FEDERAL AVIATION ADMINISTRATION LIGHTNING PROTECTION MODULES DESIGNED FOR LEADLESS DEVICES

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May 1980

Prepared for

U.S. DEPARTMENT OF TRANSPORTATION
FEDERAL AVIATION ADMINISTRATION
Systems Research & Development Service
Washington, D.C. 20590

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16. Abstract

The silicon avalanche diode transient suppressor is widely used to protect low level solid state devices against voltage transients. There has been a problem, however, in providing suitable low loss, low inductive installation mountings especially in retrofit cases. This report describes two mounting systems developed for the FAA, a barrier strip designated FA9455, for direct current, pulsed or audio lines and coaxial holder designated FA9479 for 50 or 72 ohm video or F.R. lines. Tests were performed using both conventionally constructed suppressors and low capacity units at voltage ratings varying from 6.8 volts to over 50 volts and including bipolar and unipolar devices. Square wave tests on the barrier strip, insertion loss tests on the coaxial module and surge testing of both modules indicated that within test parameters, the devices are limited only by the capabilities of the surge suppressor used. i.e. They are device limited.

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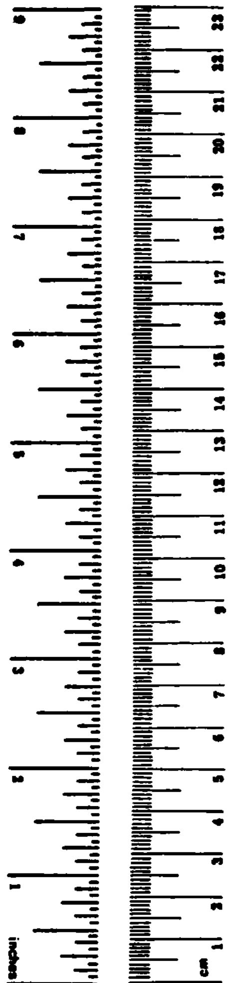
309050

METRIC CONVERSION FACTORS

Approximate Conversions to Metric Measures

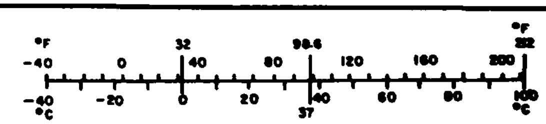
Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
in	inches	*2.5	centimeters	cm
ft	feet	30	centimeters	cm
yd	yards	0.9	meters	m
mi	miles	1.6	kilometers	km
		AREA		
in^2	square inches	6.5	square centimeters	cm^2
ft^2	square feet	0.09	square meters	m^2
yd^2	square yards	0.8	square meters	m^2
mi^2	square miles	2.6	square kilometers	km^2
	acres	0.4	hectares	ha
		MASS (weight)		
oz	ounces	28	grams	g
lb	pounds	0.45	kilograms	kg
	short tons (2000 lb)	0.9	tonnes	t
		VOLUME		
tsp	teaspoons	5	milliliters	ml
Tbsp	tablespoons	15	milliliters	ml
fl oz	fluid ounces	30	milliliters	ml
c	cups	0.24	liters	l
pt	pints	0.47	liters	l
qt	quarts	0.95	liters	l
gal	gallons	3.8	liters	l
ft^3	cubic feet	0.03	cubic meters	m^3
yd^3	cubic yards	0.76	cubic meters	m^3
		TEMPERATURE (exact)		
°F	Fahrenheit temperature	5/9 (after subtracting 32)	Celsius temperature	°C

*1 in ≡ 2.54 (exactly). For other exact conversions and more detailed tables, see NBS Misc. Publ. 286, Units of Weights and Measures, Price $2.25, SD Catalog No. C13.10:286.



Approximate Conversions from Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
mm	millimeters	0.04	inches	in
cm	centimeters	0.4	inches	in
m	meters	3.3	feet	ft
m	meters	1.1	yards	yd
km	kilometers	0.6	miles	mi
		AREA		
cm^2	square centimeters	0.16	square inches	in^2
m^2	square meters	1.2	square yards	yd^2
km^2	square kilometers	0.4	square miles	mi^2
ha	hectares (10,000 m^2)	2.5	acres	
		MASS (weight)		
g	grams	0.035	ounces	oz
kg	kilograms	2.2	pounds	lb
t	tonnes (1000 kg)	1.1	short tons	
		VOLUME		
ml	milliliters	0.03	fluid ounces	fl oz
l	liters	2.1	pints	pt
l	liters	1.06	quarts	qt
l	liters	0.26	gallons	gal
m^3	cubic meters	35	cubic feet	ft^3
m^3	cubic meters	1.3	cubic yards	yd^3
		TEMPERATURE (exact)		
°C	Celsius temperature	9/5 (then add 32)	Fahrenheit temperature	°F



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*TM, General Semiconductor Industries

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This report was prepared by the Department of Electrical Engineering, Florida Institute of Technology as a participant in the Post Doctoral Program at the Rome Air Development Center. The effort was conducted via RADC Job Order No. 9567 for the Federal Aviation Administration under Contract No. DOT-FA 72 WAI-356. The Contract was administered under the direction of Mr. Fred S. Sakate, ARD 350, FAA Washington, D.C. The tests were directed by Richard M. Cosel. The author wishes to acknowledge with thanks the assistance of Mr. J. T. Pizzicaroli of General Semiconductor Industries in performing certain surge tests, Mr. Larry Sadler of the Harris Corporation in providing insertion loss data, Mr. Keith Huddleston, Georgia Institute of Technology for loan of his surge generator and Mrs. Marjorie Quaiel for preparation of the final manuscript.

CHAPTER I

INTRODUCTION

The use of silicon avalanche diodes for suppression of induced transients has been widely documented. The standard low power units which appeared on the market were packaged much the same as ordinary rectifier diodes, i.e., axial or stud mounting. While these were reasonably simple to wire into existing circuitry, several inherent problems surfaced. The problems mainly involved the packaging (physical arrangement) to provide protection at line termination points such as the demarcation box at a facility entrance, and the inductance (which could be significant) added by device leads.

The FAA, recognizing these problems decided to attack on both fronts simultaneously. First of all in conjunction with General Semiconductor Industries, a family of leadless devices was developed. These devices - Figure I - are now catalog items (1) in breakdown voltages ranging from 6 to 115 volts in both unipolar and bipolar form. Also available are low capacity units (2) which have been tested for insertion loss at frequencies up to 1.0gHz.

The second task, a logical outgrowth of the first was to develop a family of suitable holders or modules which meet the following goals:

Ease of installation
Minimum lead length
Use with single or multiple twisted pair lines
Use with coaxial lines

Through the RADC Post Doctoral Program, Florida Institute of Technology was given the task of development of both a holder which would replace the typical barrier strip and a second unit for use in coaxial line. The resulting barrier strip shown in Figure 2, A and B is made in two lengths. The FA9455A is a five device unit while the B version holds 10 devices. Illustration 2A shows a module with components for a

typical protection circuit in stages of installation. While five or ten devices can be accommodated, this does not necessarily equate to five or ten lines. The size and shape of the diode inserts were specifically selected so that the unit would be interchangeable with available miniature gas tubes. Thus in a more complex suppression circuit, two or more positions can be used with one line. The crossover connector provided is shown at the top.

The coaxial module FA9479 Figure 3, was fabricated using a standard UG 28A/U type N Tee. As can be seen from the illustration, the throughput goes through the head of the Tee and the protection device is in the modified leg. The center line connector has been replaced with a flat head screw and insulating cup. The low capacity units available in the leadless configuration were unipolar devices. In order to accommodate two diodes for bipolar operation, the cap was redesigned, extended to provide added space. Orginally a conical spring was used as the internal contact. However, because the spring had too much inductance the cap was redesigned to make use of a flat belleville washer type spring. In production, the adjustable screw would be replaced with a fixed contact.

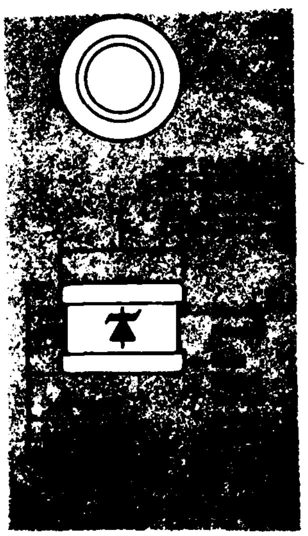


Figure I
General Semiconductor Leadless TransZorb c

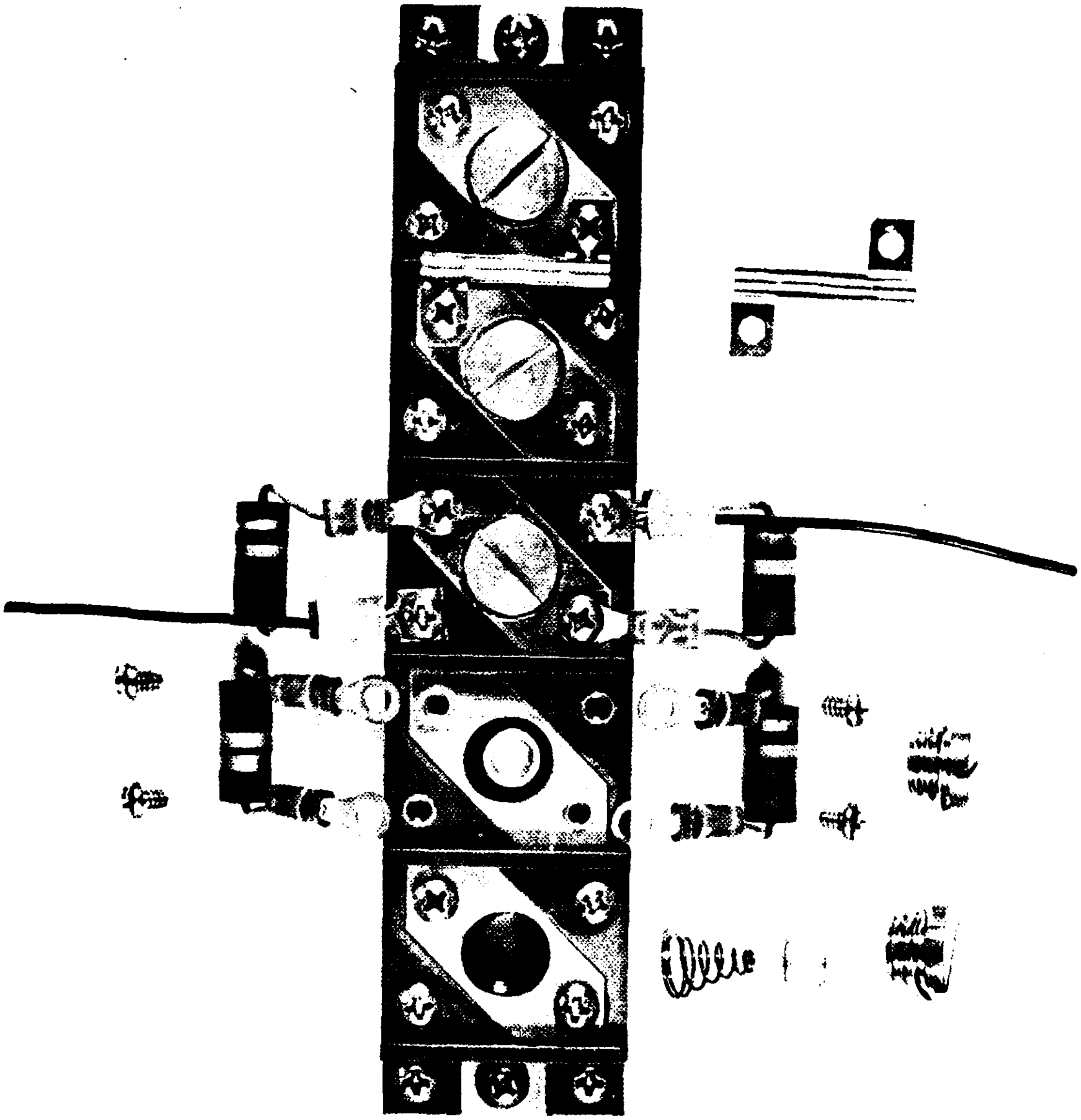
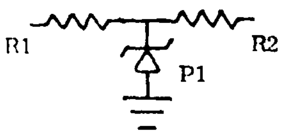


Figure 2A

Lightning Protection Module (LPM) FA9455A showing diode insertion and resistor mounting for the most common arrangement.

Resulting Circuit



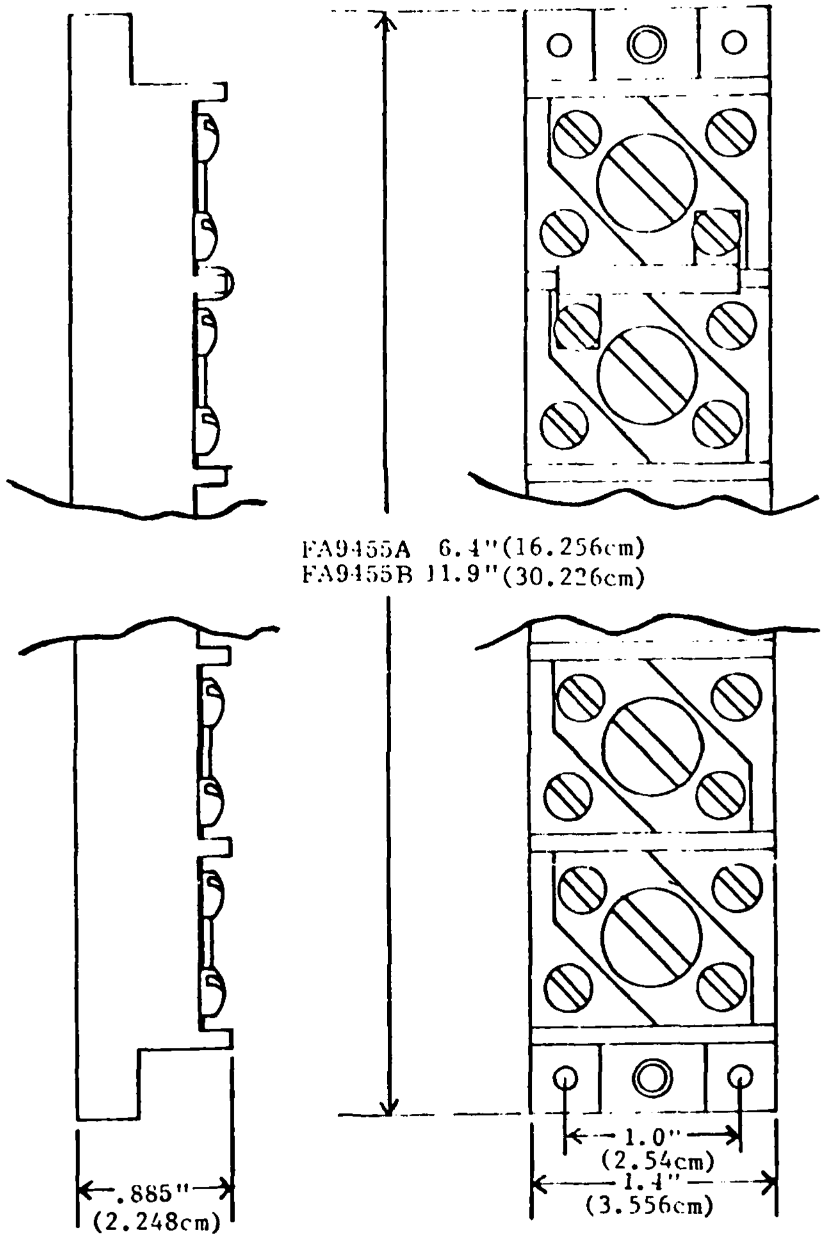


Figure 2B

Lightning Protection Module, Plan View

The 5 Terminal unit is designated FA9455A

The 10 Terminal unit is designated FA9455B

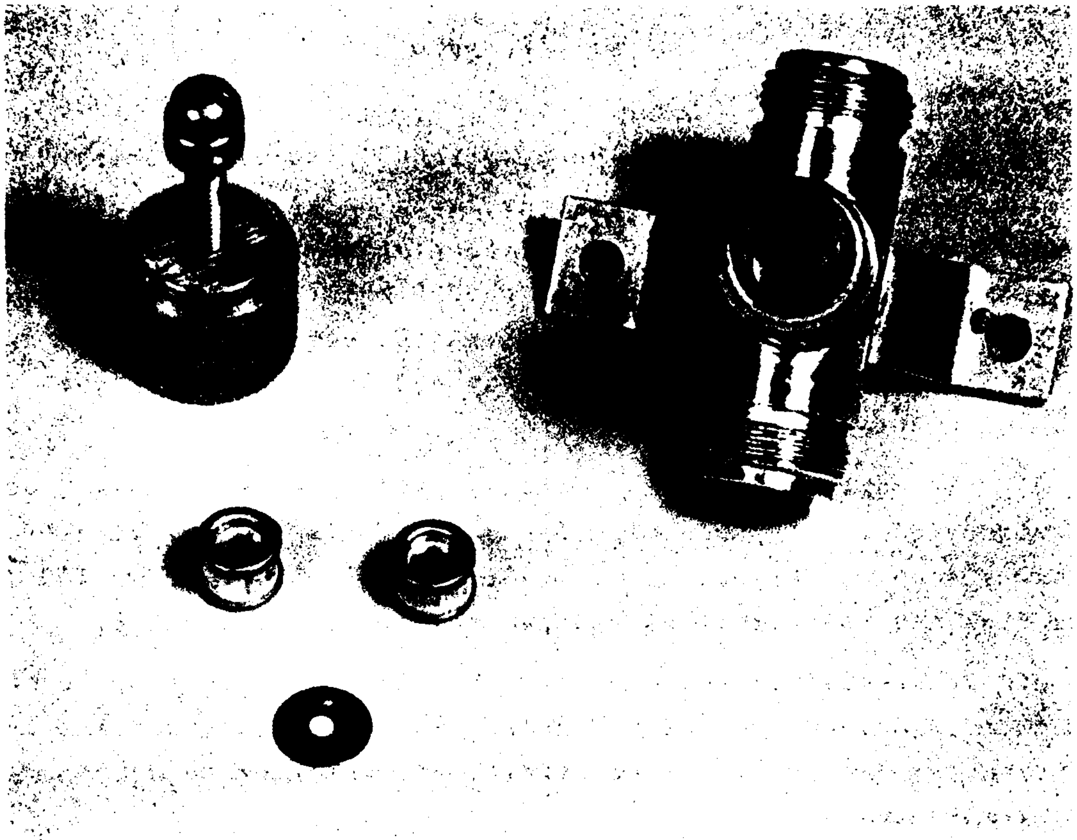


Figure 3

FA 9479

Lightning Protection Module, Coaxial (LPMC)

Note that a cupped "belleville" type washer has been substituted for the conical spring washer substantially reducing inductance effects. Space for two suppression devices has been extended using a redesigned cap. In production, the adjustable screw contact would be replaced by a fixed contact.

CHAPTER 2

TEST PROGRAM

2.1 Lightning Protection Module, FA9455 (Barrier Strip)

Suppression Characteristics, such as peak power dissipation and breakdown voltage of the protective devices are listed in appropriate catalogs. (1) Of specific interest in applying the devices to existing circuits is the effect the device and its holder may have on the quality and level of the signal being transmitted.

The barrier strip is commonly used to connect single or twisted pair telephone type lines. Signals include pulsed d.c. and sinusoidal signals from low frequency power (60 or 400 Hertz) and control lines and the audio frequency range.

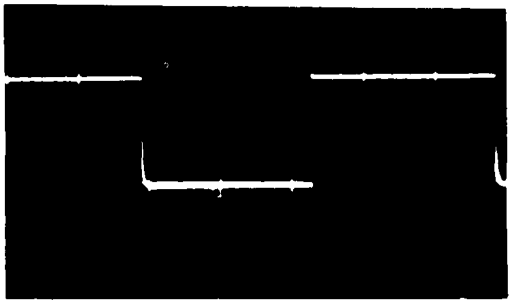
In special cases, clock synchronization pulses up to 10MHz are accommodated on twisted pair. However, the input and output circuitry is specially conditioned and designed to accommodate degraded pulse shapes.

2.1.1 Square Wave Tests

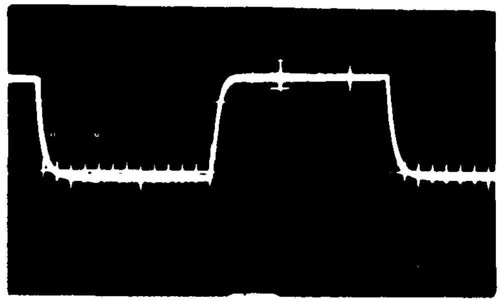
A series of square wave tests were run using both standard and low capacity diodes. Degradation effect of the lines themselves was minimized by using short leads and no termination in order to picture solely the effect of the suppression device in combination with the module. The square wave pulse generator used was a Hewlett Packard 211A with a maximum frequency of 1 MHz and an output of 55 volts across a 600Ω internal impedance. The rise time specification is less than .1μ sec.

The barrier strip was tested using the following devices: 1.5KC7.5, 1.5KC36, 1.5KC51, GZ92111A, GZ92111B and the GZ60316B. All are unipolar devices. Tests with available bipolar units showed no significant differences. Test results are shown in figures 4 through 10. In each case the test voltage shown is just

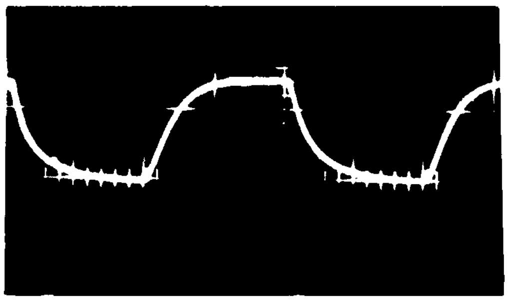
below the clipping point unless otherwise indicated. It is interesting to note that in this "large signal" test case, with the exception of the 6.8 volt device, GZ60316B, the apparent square wave distortion is related more to the device voltage rating than to the diode "low signal" capacitance. Thus the 36 volt devices 1.5KC36 (standard capacity) and the GZ92111A (low capacity), show essentially similar wave shapes at corresponding frequencies. The GZ60316Bs, low capacity devices of earlier manufacture had all been subjected to extensive surge testing and exhibited rounded zener knees indicative of leakage. The insertion loss curve, Figure 21, also shows an apparent reson nce effect which seems to be unique to the construction of this particular series. Figures 11A and B shows the comparison of the 'knees' of the GZ60316B and GZ921111A both to the same scale of 5 volts/division. Figure 11C shows the 'knee' of the GZ60316B somewhat expanded at 2 volts /division.



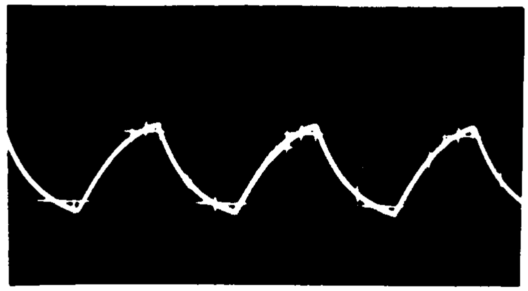
1. 1000 H_Z
   5 v/cm, 100 μsec x 2



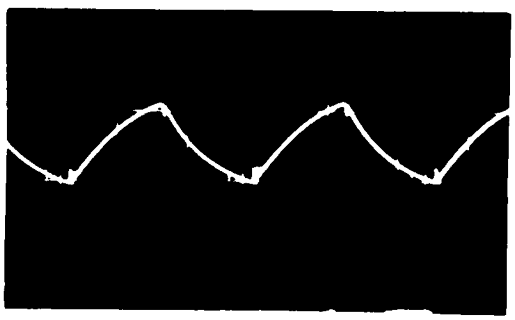
2. 10 KH_Z
   5 v/cm, 10 μsec x 2



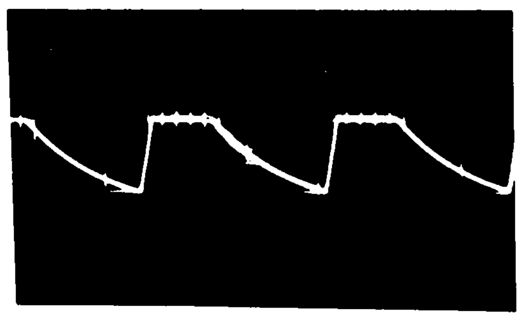
3. 50 KH_Z
   5 v/cm, 1 μsec x 5



4. 100 KH_Z
   5 v/cm, 1 μsec x 5



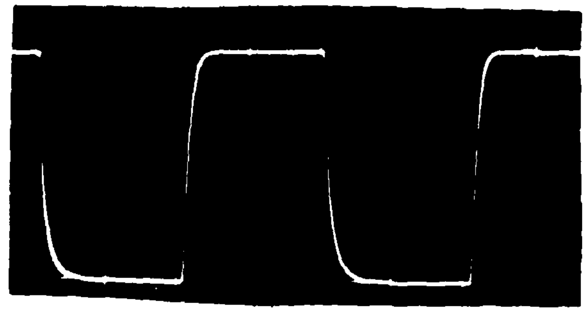
5. 200 KH_Z
   5 v/cm, 1 μsec x 2



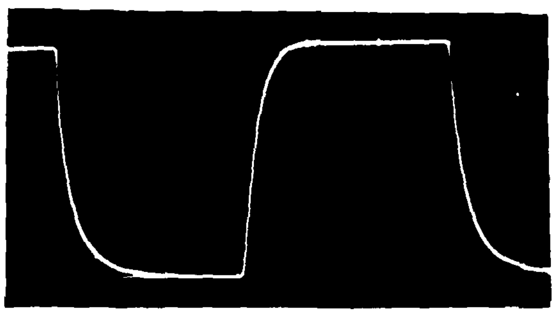
6. 200 KH_Z
   5 v/cm, 1 μsec x 2
   (Showing Clipping Action)

Figure 4
Square Wave Test
1.5KC7.5 (V_B 7.76) Mounted in LPM 9455A

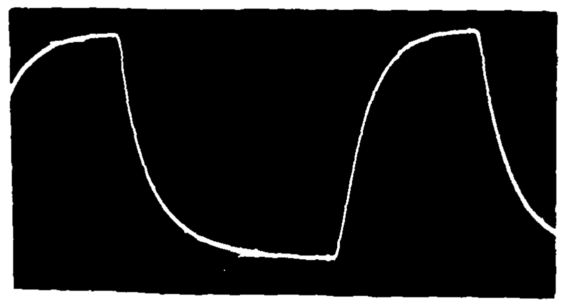
1. 1000 Hz
10 v/cm, 100 µsec x 2



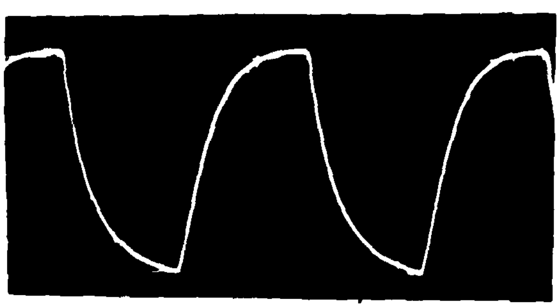
2. 50 KHz
10 v/cm, 1 µsec x 5



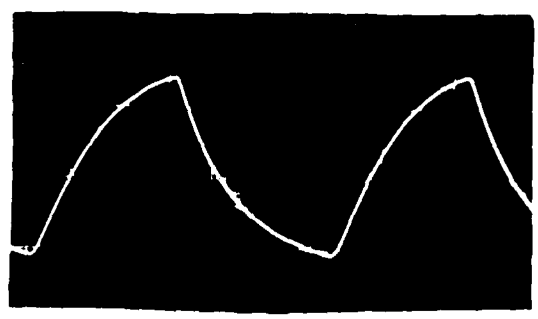
3. 100 KHz
10 v/cm, 1 µsec x 2



4. 200 KHz
10 v/cm, 1 µsec x 1

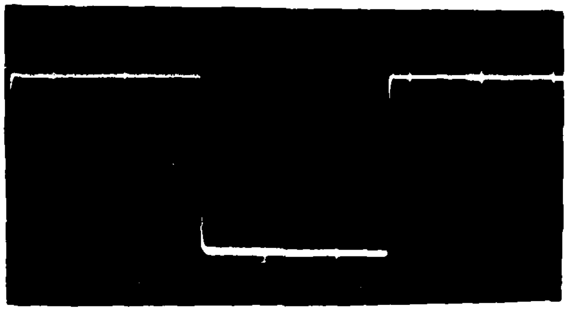


5. 300 KHz
10 v/cm, 1 µsec x 1

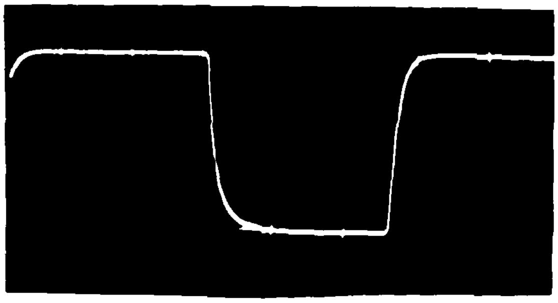


6. 500 KHz
10 v/cm, .1 µsec x 5

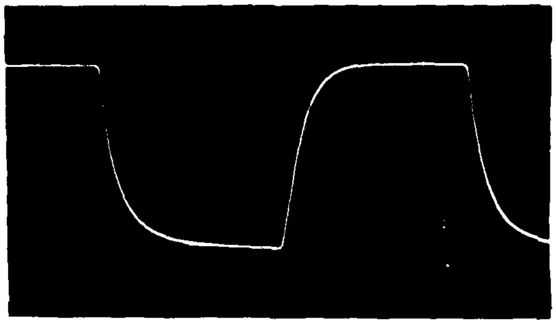
Figure 5
Square Wave Test
1.5KC36 (V_B 33.36) Mounted in LPM 9455A



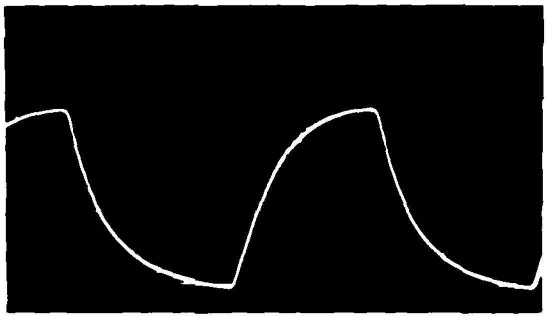
1. 10 KHz
20 v/cm, 10 μsec x 2



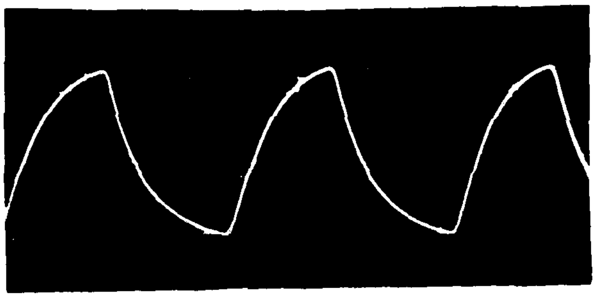
2. 100 KHz
20 v/cm, 1 μsec x 2



3. 200 KHz
20 v/cm, 1 μsec x 1

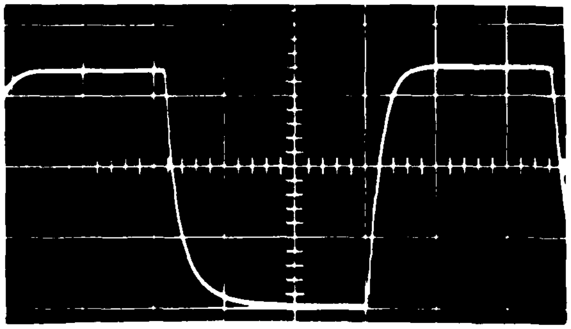


4. 500 KHz
20 v/cm, .1 μsec x5

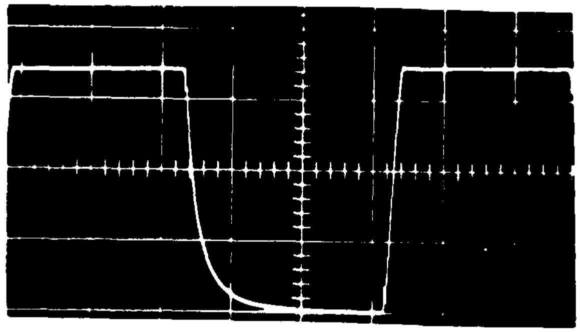


5. 650 KHz
20 v/cm, .1 μsec x 5

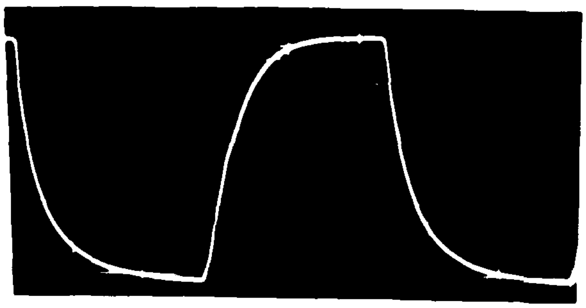
Figure 6
Square Wave Test
1.5KC51 (V_B 52.65) Mounted in LPM 9455A



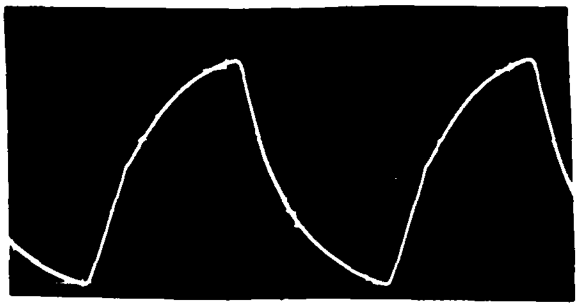
1. 100 KHz
10 v/cm, 1 µsec x 2



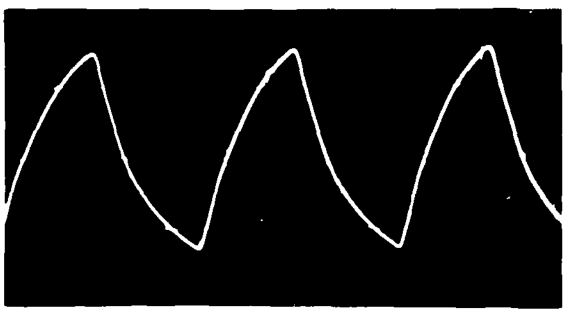
2. 100 KHz (Showing Clipping)
10 v/cm, 1 µsec x 2



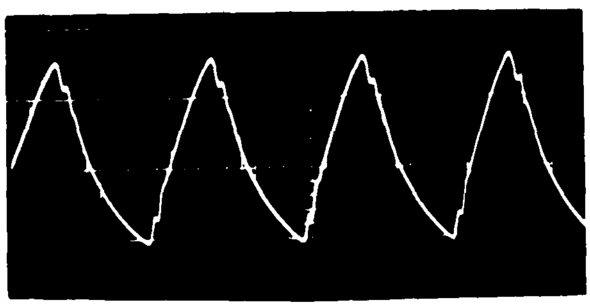
3. 200 KHz
10 v/cm, 1 µsec x 1



4. 500 KHz
10 v/cm, .1 µsec x 5

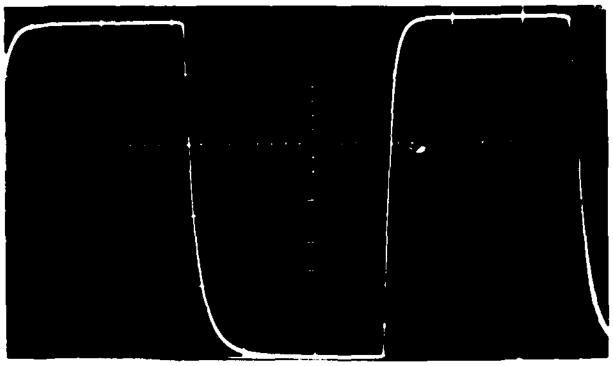


5. 750 KHz
10 v/cm, .1 µsec x 1

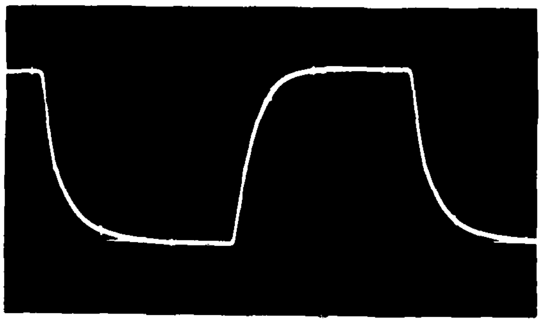


6. 1000 KHz
10 v/cm, .1 µsec x 5

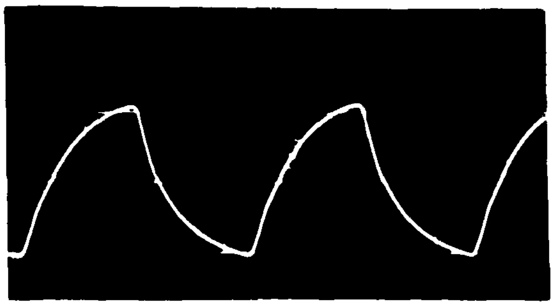
Figure 7
Square Wave Test
GZ 92111A (V_B 35.1v) Mounted in LPM 9455A



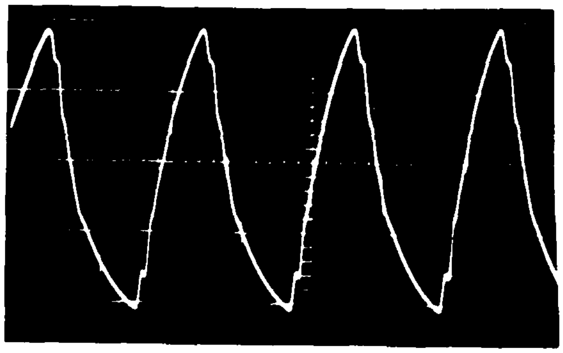
1. 100 KHz
10 v/cm, 1 µsec x 2



2. 200 KHz
20 v/cm, 1 µsec x 1

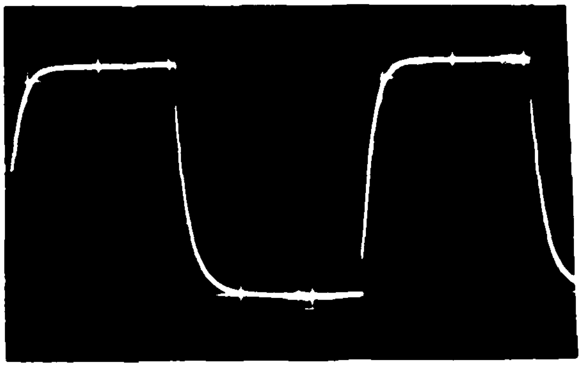


3. 650 KHz
20 v/cm, .1 µsec x 5

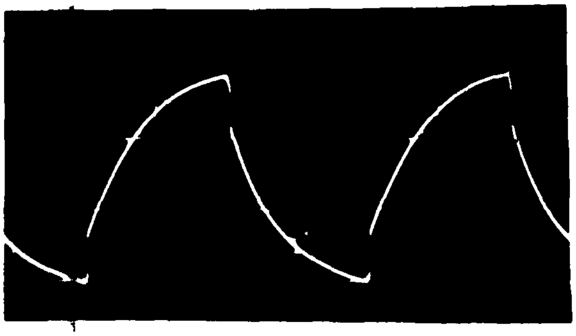


4. 1000 KHz
10 v/cm, .1 µsec x 5

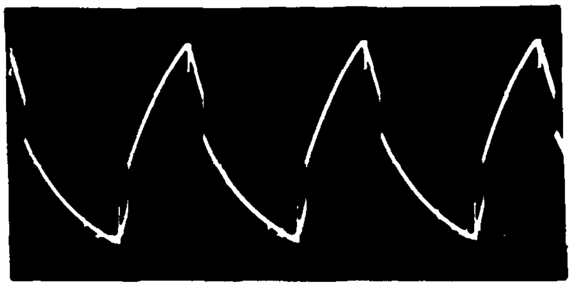
Figure 8
GZ 92111B (V_B 50.4) Mounted in LPM 9455A



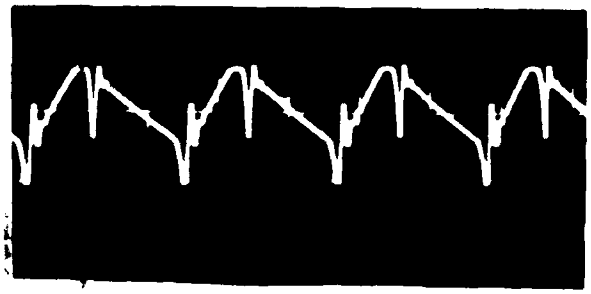
1. 10 KHz
   2 v/cm, 10 µsec x 2



2. 50 KHz
   2 v/cm, 1 µsec x 5



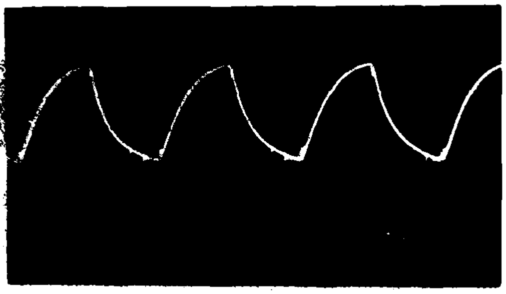
3. 200 KHz
   2 v/cm, 1 µsec x 2



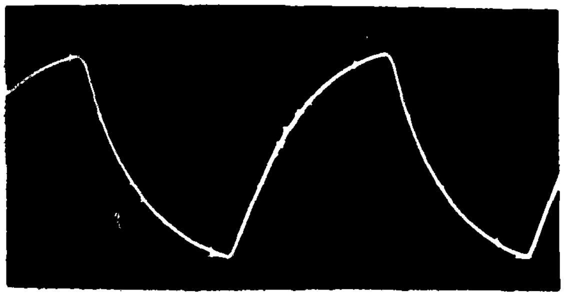
4. 1000 KHz
   2 v/cm, .1 µsec x 5

Figure 9

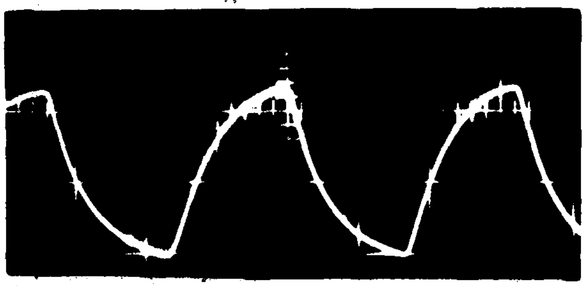
GZ 60316B (V_B 6.8v) Mounted in LPM 9455A



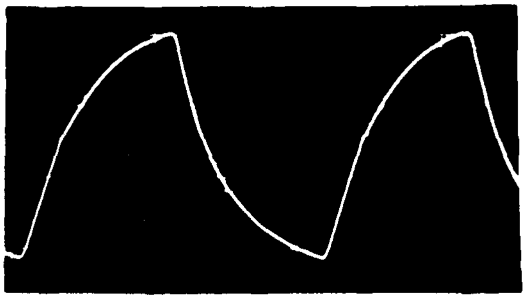
1. 1.5KC7.5 100 KHz
5 v/cm, 1 µsec x 5



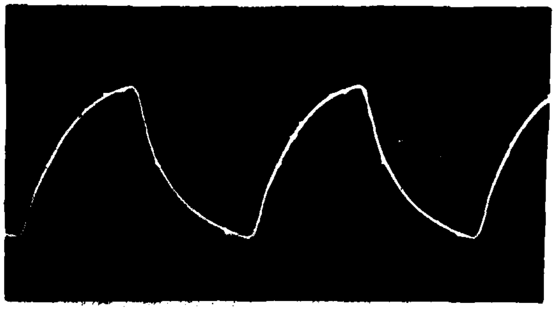
2. 1.5KC36 500 KHz
10 v/cm, .1 µsec x 5



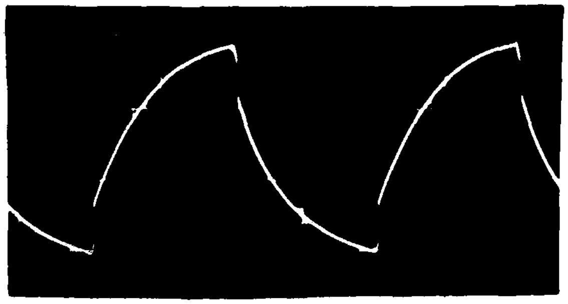
3. 1.5KC51 650 KHz
20 v/cm, .1 µsec x 5



4. GZ92111A 500 KHz
10 v/cm, .1 µsec x 5

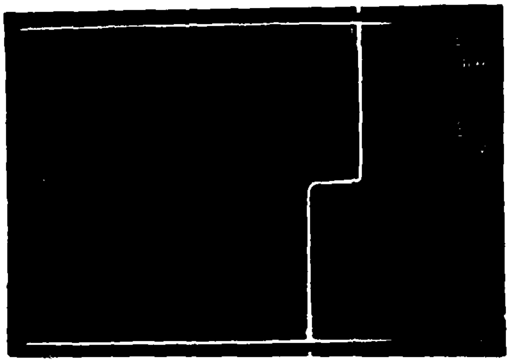


5. GZ92111B 650 KHz
20 v/cm, .1 µsec x 5

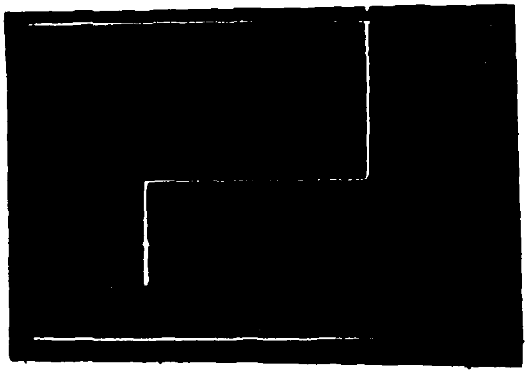


6. GZ60316B 50 KHz
2 v/cm, 1 µsec x 5

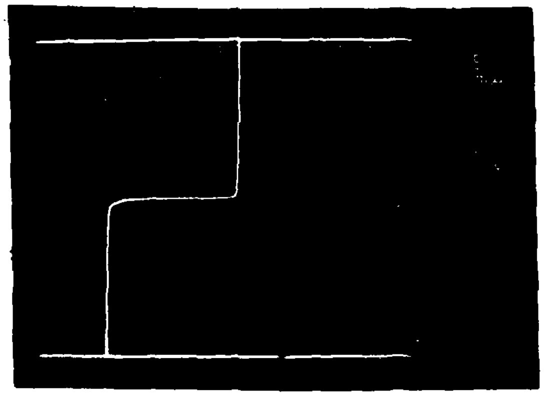
Figure 10



A



B



C

Figure 11

Zener Curves
A and C GZ60316B
B GZ92111A

2.1.2 Surge Tests

Surge testing was performed using a laboratory fabricated generator, courtesy of G.K. Huddleston, Georgia Institute of Technology. The basic test circuit is shown in Figure 12.

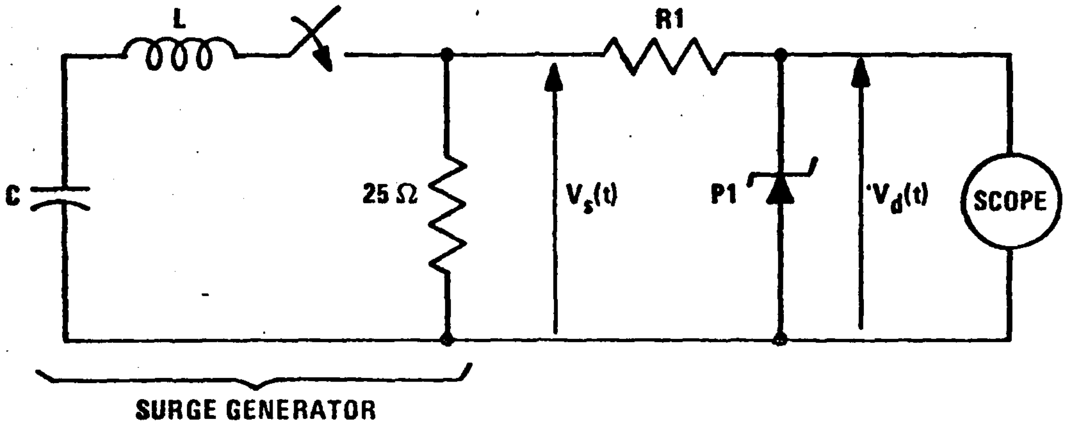


Figure 12

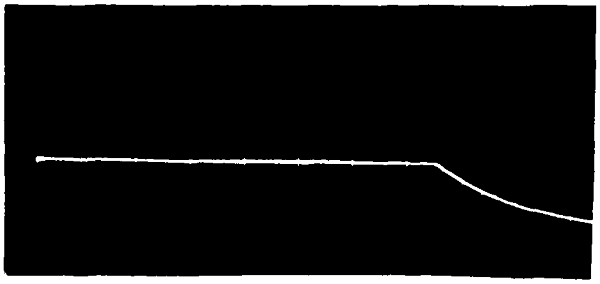
C = 67.5 Mfd, 1200 Volt
V_s = 1000 Volts
V_D = Dependent on device
R_1 = 120Ω

Figure 13 shows a typical response curve, effectively a 10 X 1000 waveform.

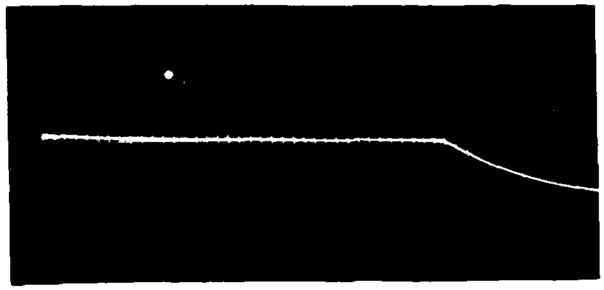
200 Volts/cm
1 millisecond/cm

Figure 13

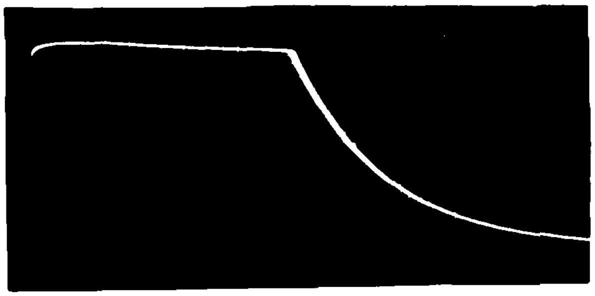
The output of the surge generator was connected to the barrier strip through an 18" length of RG58 coaxial cable. The oscilloscope, barrier strip and surge generator shared a common ground. Tests were conducted using a representative group of leadless TransZorbs with the conical coil spring internal contact furnished with the LPMs.



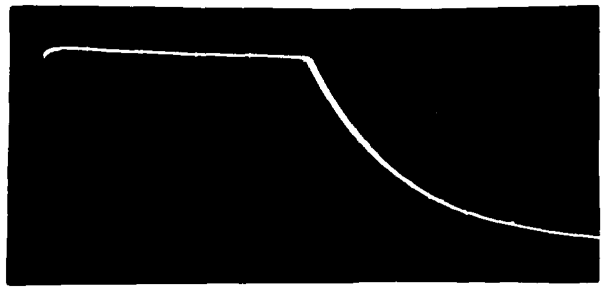
A. 1.5 KC 7.5 5 V/cm



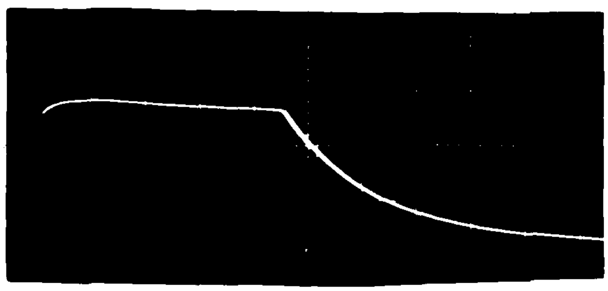
B. 1.5 KC 7.5C 5 V/cm



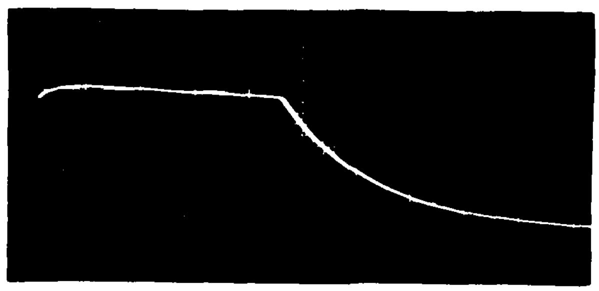
C. 1.5 KC 36 10 V/cm



D. 1.5 KC 36C 10 V/cm



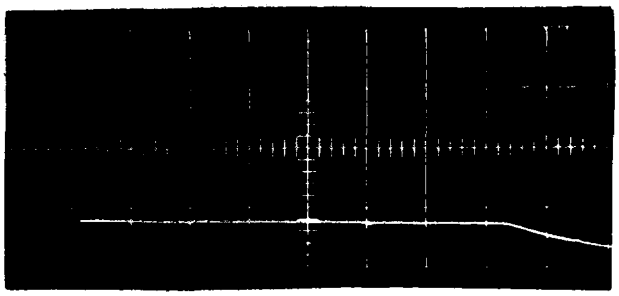
E. 1.5 KC 51 20 V/cm



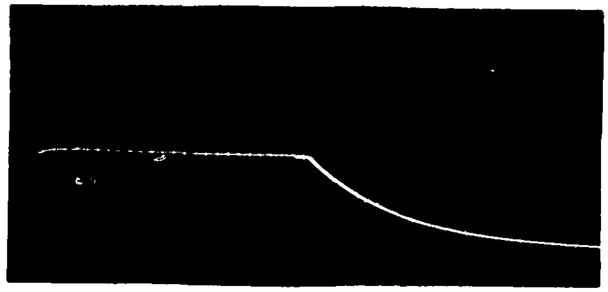
F. 1.5 KC 51C 20 V/cm

Figure 14

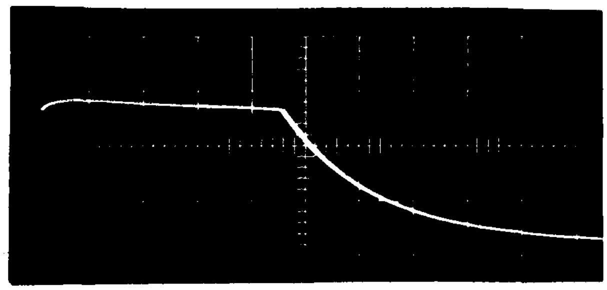
Stock TransZorbs (C= Bipolar)
Mounted in FA9455A
V_s + 1000 Volts $R_1 = 120\Omega$



A. GZ60316B 10 V/cm



B. GZ92111A 20 V/cm



C. GZ92111B 20 V/cm

Figure 15

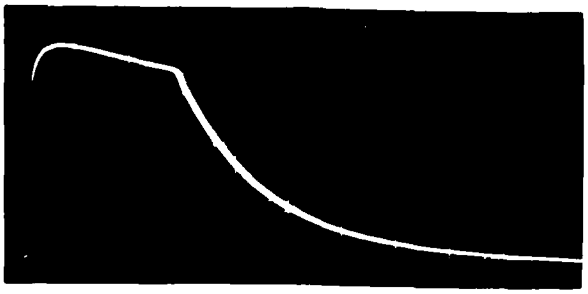
Low Capacity Unipolar Units
Mounted in FA9455A
V_s = 1000 Volts R_1 =120Ω

Also tested were two Joslyn leadless gas tube supressors and two transient suppressors with leads. All results are shown graphically in the following series of photographs. It can be seen that all units clamped essentially within tolerance limits.

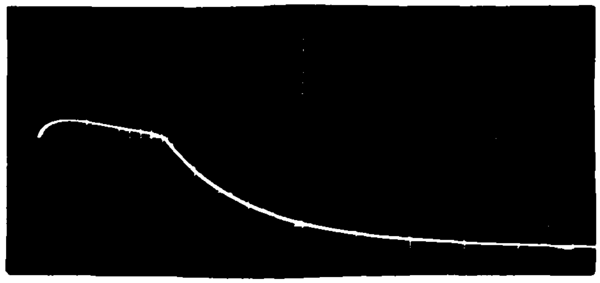
The discharge curves for the unipolar and bipolar devices are essentially the same. Apparent differences in peak values can be attributed to jitter in the vertical amplifier of the oscilloscope.

Two devices with leads were connected using maximum lead length, totaling 2 inches. Results are pictured in Figure 16. Note the accentuated peak occurring in the first milliscecond of clamping.

As shown in Figure 17 gas tube devices essentially show a short circuit during conduction. When conduction ceases, voltage rises to the point determined by the discharge characteristic. For low voltage circuit protection they are normally used in combination with a silicon avalanche diode or devices with similar low voltage protection capability. The FA9455 LPMs will readily accept the Joslyn two electrode miniture gas tube surge protectors and those of other manufacturers with similar dimensions.



A. 1N5662A 50 V/cm

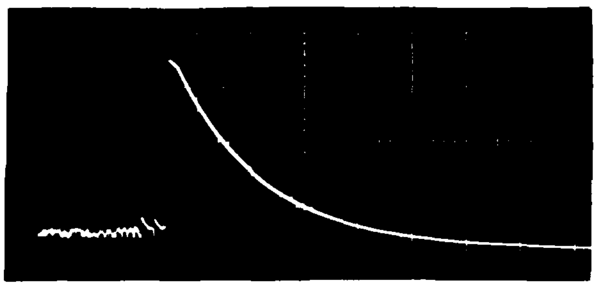


B. 1.5 KE200CA 100 V/cm

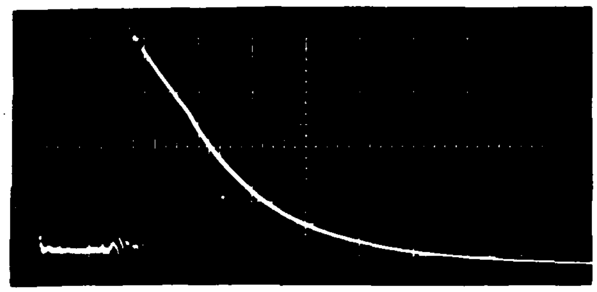
Figure 16

Avalanche Diodes With Leads

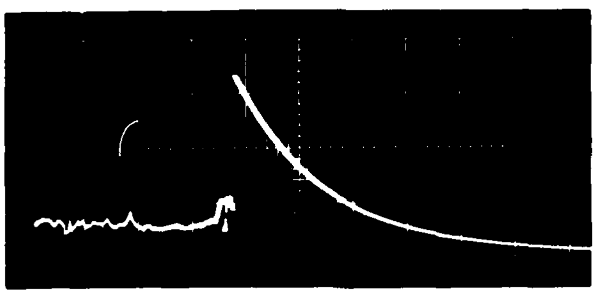
V_s= 1000 Volts R_1 = 120Ω



A. Joslyn 2022-12* 50 V/cm



B. Joslyn 2021-12* 50 V/cm



C. NE-51 20 Vcm

Figure 17

Gas Tube Devices in FA9455A

V_s= 1000 Volts R_1 = 120Ω

* Leads Removed

2.2 Lightning Protection Module, Coaxial, FA9479

2.2.1 Insertion Loss Tests

The coaxial module alone and in combination was tested for insertion loss at frequencies ranging from 10 MHz to 1 GHz. The devices used in conjunction with the module were pairs; GZ60316B, V_b 6.8v nominal; GZ92111A, 36v nominal; and GZ92111B, V_b 51v nominal. Tests were performed on a Hewlett Packard 8507B Automatic Network Analyzer through the courtesy of the Harris Corporation. Results are tabulated in Tables 1, 2, 3, and 4. Table 5 is the calibration check. Results are plotted graphically in Figures 18, 19, 20 and 21. The GZ92111A's and GZ92111B's both exhibit smooth rising curves with the higher voltage device exhibiting less loss because of its lower junction capacitance. The much lower voltage GZ60316B Figure 21, has a sharply pronounced peak loss at approximately 370 MHz indicative of leakage and a possible resonance in the low capacity diode circuit incorporated in the device.

Depending on application, either insertion loss or VSWR may be used as the criteria for maximum usable frequency. An insertion loss of 3db or a VSWR of 1.5 to 1 are commonly used (but not equivalent) limits, 3db being the half power point while a VSWR of 1.5 to 1 yields 96% power transmission. Referring to the printouts from the Network Analyzer note that the insertion (transmission) loss is provided directly. VSWR is derived from the return loss using nomographs for VSWR. (3) It should be noted that the second column of the printout which identifies the transmission loss does not include the power dissapated in the device. It is not the complement of the return loss and therefore cannot be used to enter the nomograph to obtain the VSWR. (i.e., It is not the "Transmission Loss" as defined in the nomograph). The transmission loss in the column indicates the

percentage of power which gets past the LPM to the load. The method of measuring the return loss using reflected power is consistent with the requirement of the nomograph and is used to find the VSWR. For a further discussion, see Appendix A.

An insertion loss curve for a module without diodes is shown in Figure 18. Note that the module alone at one GHz shows less than 1db insertion loss. Curves for the coaxial modules with low capacity diodes are shown in Figures 19, 20 and 21. Table 6 shows the results for the module with pairs of low capacity diodes in bipolar configuration.

TABLE 6

Protection	96% Transmission or 1.5:1 VSWR	50% Transmission Point or 3db Insertion Loss
2 GZ60316B	30 MHz	110 MHz
2 GZ92111A	170 MHz	690 MHz
2 GZ92111B	270 MHz	850 MHz

FREQUENCY	RETURN LOSS INPUT (S11)		TRANS. LOSS FORWARD (S21)		TRANS. LOSS REVERSE (S12)		RETURN LOSS OUTPUT (S22)	
MHZ	DB	ANG	DB	ANG	DB	ANG	DB	ANG
			TYPE "N" MODIFIED TEE					
10.000	42.3	-110.7	0.00	-0.7	0.00	-0.8	43.4	-81.8
35.000	35.6	-77.0	0.00	-2.6	0.00	-2.6	35.6	-72.9
60.000	31.9	-82.5	0.00	-4.4	0.00	-4.5	33.4	-109.3
85.000	28.8	-86.1	0.01	-6.3	0.01	-6.3	32.9	-148.0
110.000	26.3	-98.7	0.01	-8.1	0.02	-8.1	32.6	165.3
135.000	25.5	-114.6	0.01	-9.8	0.01	-9.8	31.4	125.6
160.000	27.5	-119.3	0.01	-11.7	0.01	-11.7	28.1	73.8
185.000	28.1	-91.3	0.01	-13.6	0.02	-13.7	26.2	23.7
210.000	23.4	-92.9	0.02	-15.5	0.03	-15.3	24.6	-26.8
235.000	21.7	-105.3	0.04	-17.3	0.04	-17.4	22.9	-66.9
260.000	21.7	-110.3	0.04	-19.1	0.04	-19.2	21.2	-97.3
285.000	21.2	-105.9	0.05	-21.0	0.05	-21.0	19.8	-123.1
310.000	20.0	-104.2	0.06	-22.9	0.06	-22.9	19.0	-150.1
335.000	19.0	-101.9	0.08	-24.9	0.08	-24.9	18.3	-176.0
360.000	17.7	-100.4	0.09	-26.2	0.09	-26.1	18.4	154.8
385.000	16.6	-103.0	0.10	-28.7	0.10	-28.1	18.3	119.1
410.000	15.7	-105.1	0.11	-30.9	0.13	-29.9	18.4	76.3
435.000	14.4	-110.1	0.14	-32.9	0.14	-32.8	18.6	31.4
460.000	13.6	-119.8	0.18	-34.9	0.18	-34.8	19.1	-13.5
485.000	14.2	-128.5	0.17	-36.7	0.18	-36.5	18.5	-46.2
510.000	15.2	-128.9	0.18	-38.6	0.17	-38.5	17.0	-76.0
535.000	14.9	-124.1	0.21	-40.7	0.21	-40.7	14.8	-106.8
560.000	14.0	-124.1	0.26	-42.5	0.26	-42.6	13.1	-138.6
585.000	13.2	-123.0	0.27	-44.2	0.28	-44.5	12.2	-168.0
610.000	11.8	-124.8	0.30	-46.1	0.31	-46.3	11.6	165.5
635.000	10.9	-133.6	0.34	-47.5	0.33	-47.8	10.8	138.6
660.000	11.3	-141.8	0.31	-49.2	0.32	-49.6	10.7	106.7
685.000	12.1	-141.8	0.33	-51.5	0.34	-51.6	11.0	70.8
710.000	11.9	-139.4	0.39	-53.7	0.41	-53.7	11.8	33.8
735.000	11.7	-142.0	0.42	-55.6	0.42	-55.4	12.4	-2.5
760.000	12.1	-141.7	0.45	-57.7	0.45	-57.5	12.1	-39.2
785.000	11.8	-135.2	0.48	-59.8	0.49	-59.6	11.4	-77.1
810.000	10.6	-135.7	0.54	-61.7	0.55	-61.7	10.4	-116.2
835.000	10.0	-139.9	0.59	-63.7	0.61	-63.6	9.4	-152.5
860.000	9.4	-142.6	0.62	-65.4	0.64	-65.4	8.6	175.1
885.000	8.9	-147.1	0.65	-67.5	0.66	-67.4	7.8	144.2
910.000	8.7	-151.3	0.69	-69.6	0.69	-69.6	7.4	113.6
935.000	8.9	-153.2	0.74	-71.7	0.74	-71.6	7.4	83.9
960.000	8.6	-153.8	0.82	-73.9	0.83	-73.9	7.7	53.9
985.000	8.6	-155.6	0.91	-75.3	0.93	-76.0	8.0	22.7

Table 1

FREQUENCY	RETURN LOSS INPUT (S11)		TRANS. LOSS FORWARD (S21)		TRANS. LOSS REVERSE (S12)		RETURN LOSS OUTPUT (S22)	
MHZ	DB	ANG	DB	ANG	DB	ANG	DB	ANG
			GZ 92111A					
10.000	26.2	-119.6	0.19	-2.7	0.20	-2.8	25.5	-119.1
30.000	20.4	-128.3	0.50	-5.9	0.50	-6.0	20.1	-129.5
50.000	17.8	-134.9	0.76	-8.0	0.76	-8.0	17.9	-135.6
70.000	16.4	-140.7	0.95	-9.7	0.96	-9.7	16.6	-139.5
90.000	15.9	-144.9	1.08	-11.0	1.09	-10.9	15.7	-142.5
110.000	15.4	-146.5	1.17	-12.5	1.17	-12.4	15.1	-145.4
130.000	14.9	-147.3	1.25	-13.9	1.24	-13.7	14.8	-147.9
150.000	14.3	-148.9	1.31	-15.1	1.30	-15.1	14.6	-149.2
170.000	14.1	-150.3	1.34	-16.7	1.34	-16.7	14.4	-150.0
190.000	13.9	-150.3	1.40	-18.2	1.39	-18.2	14.0	-149.8
210.000	13.5	-150.1	1.45	-19.8	1.45	-19.7	13.5	-149.9
230.000	13.0	-151.2	1.49	-21.2	1.49	-21.1	13.1	-150.1
250.000	12.7	-152.2	1.52	-22.6	1.53	-22.6	12.7	-151.0
270.000	12.4	-152.2	1.57	-24.2	1.58	-24.2	12.2	-151.5
290.000	12.1	-152.9	1.63	-25.8	1.62	-25.8	11.9	-152.2
310.000	11.8	-153.2	1.68	-27.3	1.67	-27.3	11.5	-152.5
330.000	11.4	-153.9	1.72	-28.8	1.72	-28.8	11.2	-153.2
350.000	11.0	-154.5	1.77	-30.5	1.77	-30.5	11.0	-153.7
370.000	10.7	-155.0	1.83	-32.0	1.83	-31.9	10.6	-154.3
390.000	10.4	-155.8	1.89	-33.6	1.89	-33.6	10.4	-154.8
410.000	10.0	-156.8	1.94	-35.2	1.94	-35.1	10.1	-155.7
430.000	9.8	-157.9	1.99	-36.8	1.99	-36.8	9.9	-156.6
450.000	9.5	-159.5	2.07	-38.4	2.05	-38.5	9.6	-157.9
470.000	9.3	-160.1	2.12	-40.0	2.11	-40.0	9.5	-158.9
490.000	9.0	-160.5	2.19	-41.6	2.18	-41.6	9.2	-160.0
510.000	8.7	-161.5	2.25	-43.2	2.25	-43.1	9.0	-160.9
530.000	8.4	-163.0	2.32	-44.1	2.33	-44.7	8.7	-161.8
550.000	8.2	-164.3	2.39	-45.7	2.40	-46.1	8.4	-163.0
570.000	7.9	-165.8	2.50	-47.2	2.49	-47.7	8.2	-164.7
590.000	7.6	-167.7	2.59	-48.7	2.57	-48.7	7.9	-166.2
610.000	7.5	-169.9	2.67	-50.2	2.65	-50.2	7.7	-167.6
630.000	7.4	-170.5	2.76	-51.6	2.76	-51.7	7.5	-168.8
650.000	7.3	-171.1	2.85	-52.9	2.84	-53.1	7.2	-169.7
670.000	7.0	-172.2	2.94	-54.5	2.94	-54.7	7.1	-170.8
690.000	6.8	-173.6	3.00	-56.8	3.01	-56.4	6.8	-172.6
710.000	6.6	-175.1	3.11	-58.6	3.12	-58.0	6.7	-173.6
730.000	6.4	-176.2	3.22	-60.2	3.21	-59.5	6.6	-175.0
750.000	6.2	-178.0	3.33	-62.0	3.32	-61.3	6.4	-176.3
770.000	6.0	179.9	3.45	-63.6	3.45	-63.4	6.3	-177.5
790.000	5.9	178.4	3.57	-65.4	3.57	-65.2	6.1	-178.8
810.000	5.8	177.2	3.71	-67.0	3.71	-66.6	5.8	179.7
830.000	5.6	175.7	3.85	-68.4	3.84	-68.1	5.6	178.2
850.000	5.5	174.1	3.98	-69.9	3.99	-69.4	5.5	176.3
870.000	5.3	172.8	4.12	-71.5	4.12	-71.0	5.3	174.7
890.000	5.2	171.4	4.25	-72.7	4.25	-72.3	5.1	173.0
910.000	4.9	170.1	4.38	-74.1	4.38	-73.7	5.0	171.5
930.000	4.7	167.9	4.55	-75.6	4.55	-75.3	4.8	169.8
950.000	4.6	166.0	4.71	-76.9	4.72	-76.8	4.6	168.2
970.000	4.5	164.1	4.89	-78.4	4.91	-78.2	4.5	166.5
990.000	4.3	162.3	5.10	-79.7	5.11	-79.6	4.4	165.0

Table 2

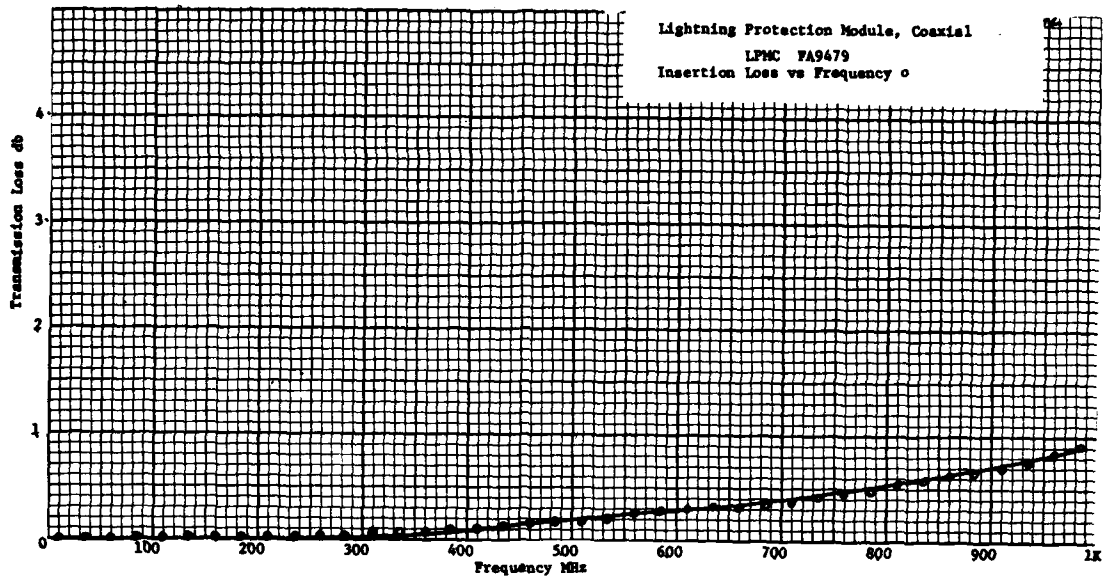


Figure 18

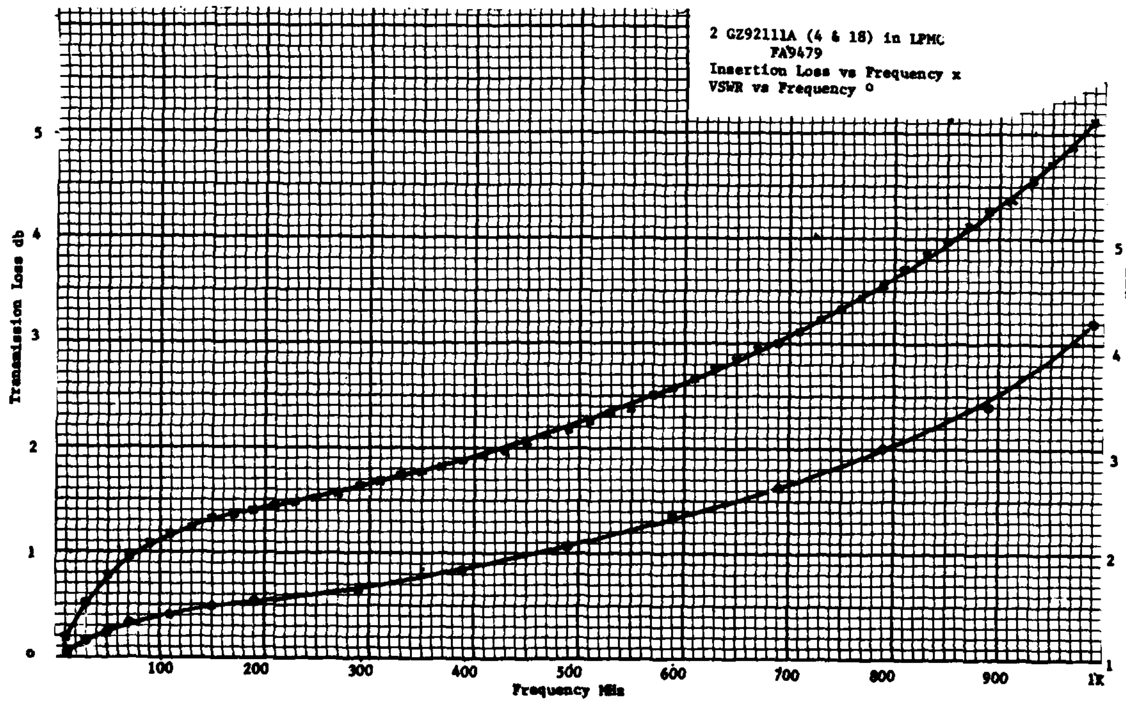


Figure 19

FREQUENCY	RETURN LOSS INPUT (S11)		TRANS. LOSS FORWARD (S21)		TRANS. LOSS REVERSE (S12)		RETURN LOSS OUTPUT (S22)	
MHZ	DB	ANG	DB	ANG	DB	ANG	DB	ANG
			GZ 92111B					
10.000	29.4	-115.3	0.11	-2.1	0.12	-2.1	28.4	-115.0
30.000	23.2	-123.5	0.33	-4.9	0.33	-5.0	22.9	-125.2
50.000	20.4	-130.0	0.51	-6.6	0.51	-6.7	20.5	-130.7
70.000	19.0	-135.4	0.63	-8.2	0.64	-8.3	19.2	-133.7
90.000	18.4	-139.2	0.72	-9.6	0.72	-9.6	18.3	-135.7
110.000	17.9	-139.5	0.77	-11.3	0.77	-11.2	17.6	-138.3
130.000	17.2	-139.4	0.82	-12.8	0.81	-12.7	17.1	-140.5
150.000	16.6	-140.7	0.85	-14.1	0.85	-14.1	16.9	-141.3
170.000	16.3	-141.7	0.87	-15.6	0.87	-15.6	16.6	-141.2
190.000	15.9	-141.0	0.91	-17.2	0.90	-17.2	16.1	-140.4
210.000	15.4	-140.4	0.94	-18.8	0.94	-18.8	15.5	-140.0
230.000	14.8	-141.6	0.98	-20.3	0.98	-20.4	14.9	-140.2
250.000	14.5	-142.4	1.00	-21.9	1.01	-21.9	14.3	-141.1
270.000	14.1	-142.3	1.04	-23.5	1.05	-23.5	13.8	-141.8
290.000	13.6	-142.7	1.09	-25.2	1.09	-25.2	13.3	-142.5
310.000	13.1	-143.2	1.12	-26.8	1.11	-26.8	12.8	-143.0
330.000	12.6	-144.1	1.16	-28.3	1.16	-28.4	12.4	-143.7
350.000	12.2	-144.7	1.21	-30.0	1.20	-30.0	12.1	-144.1
370.000	11.9	-145.4	1.25	-31.6	1.25	-31.6	11.7	-144.8
390.000	11.5	-146.3	1.29	-33.4	1.30	-33.4	11.4	-145.4
410.000	11.1	-147.7	1.34	-34.9	1.35	-34.9	11.1	-146.3
430.000	10.7	-149.0	1.38	-36.6	1.38	-36.6	10.8	-147.3
450.000	10.4	-150.7	1.44	-38.2	1.43	-38.2	10.6	-148.6
470.000	10.2	-151.3	1.48	-39.9	1.47	-39.9	10.3	-149.7
490.000	9.8	-151.7	1.54	-41.4	1.54	-41.4	10.1	-150.8
510.000	9.4	-152.8	1.59	-43.0	1.58	-43.0	9.8	-151.7
530.000	9.1	-154.5	1.64	-44.1	1.65	-44.8	9.5	-152.7
550.000	8.8	-156.0	1.71	-45.8	1.73	-46.2	9.1	-154.1
570.000	8.6	-157.6	1.79	-47.3	1.79	-47.8	8.8	-156.0
590.000	8.3	-159.6	1.87	-48.8	1.86	-48.8	8.5	-157.7
610.000	8.2	-162.0	1.93	-50.5	1.92	-50.4	8.3	-159.2
630.000	8.1	-162.4	2.01	-51.9	2.02	-52.0	8.1	-160.4
650.000	7.9	-162.7	2.09	-53.3	2.08	-53.5	7.9	-161.4
670.000	7.5	-163.8	2.15	-54.9	2.15	-55.1	7.6	-162.3
690.000	7.3	-165.4	2.20	-57.4	2.21	-57.0	7.4	-164.2
710.000	7.2	-166.7	2.29	-59.1	2.30	-58.6	7.1	-165.7
730.000	6.9	-167.9	2.38	-61.0	2.37	-60.3	6.9	-166.6
750.000	6.6	-170.1	2.47	-62.7	2.45	-62.4	6.9	-168.0
770.000	6.5	-172.2	2.55	-64.7	2.55	-63.9	6.7	-169.9
790.000	6.4	-173.6	2.65	-66.6	2.66	-66.3	6.5	-170.2
810.000	6.3	-174.7	2.77	-68.3	2.77	-67.9	6.3	-171.7
830.000	6.1	-176.0	2.88	-69.9	2.87	-69.6	6.0	-173.5
850.000	5.9	-177.6	2.99	-71.4	2.99	-71.0	5.8	-175.2
870.000	5.7	-178.9	3.09	-73.3	3.10	-72.8	5.7	-176.9
890.000	5.5	179.9	3.21	-74.7	3.21	-74.2	5.5	-178.5
910.000	5.3	178.4	3.32	-76.3	3.32	-75.9	5.3	179.9
930.000	5.1	176.2	3.45	-78.0	3.44	-77.7	5.1	178.2
950.000	4.9	174.3	3.58	-79.6	3.58	-79.5	4.9	176.5
970.000	4.8	172.5	3.71	-81.4	3.74	-81.3	4.8	175.0
990.000	4.6	170.8	3.89	-83.2	3.91	-83.0	4.6	173.5

Table 3

FREQUENCY MHZ	RETURN LOSS INPUT (S11) DB	ANG	TRANS. LOSS FORWARD (S21) DB	ANG	TRANS. LOSS REVERSE (S12) DB	ANG	RETURN LOSS OUTPUT (S22) DB	ANG
			GZ 60316B					
10.000	20.7	-108.8	0.22	-5.2	0.22	-5.3	20.4	-109.5
30.000	13.2	-115.5	0.64	-13.3	0.63	-13.4	13.2	-116.7
50.000	9.7	-122.1	1.12	-20.5	1.11	-20.5	9.7	-122.9
70.000	7.6	-128.9	1.68	-26.8	1.68	-27.1	7.5	-129.2
90.000	6.2	-135.0	2.28	-32.7	2.31	-32.7	6.0	-134.9
110.000	5.1	-140.6	2.98	-38.3	2.99	-38.1	5.0	-140.9
130.000	4.2	-146.2	3.75	-43.2	3.73	-42.9	4.2	-146.2
150.000	3.6	-151.2	4.48	-47.0	4.45	-47.0	3.6	-150.7
170.000	3.0	-156.1	5.34	-51.1	5.33	-51.2	3.1	-155.6
190.000	2.6	-160.6	6.33	-54.5	6.32	-54.5	2.6	-160.2
210.000	2.2	-165.2	7.40	-57.2	7.40	-57.2	2.3	-164.7
230.000	1.9	-169.3	8.54	-59.0	8.55	-58.9	2.0	-169.0
250.000	1.7	-173.5	9.79	-60.0	9.81	-59.9	1.7	-173.1
270.000	1.5	-177.5	11.18	-60.1	11.18	-59.9	1.5	-177.0
290.000	1.4	178.8	12.61	-58.2	12.71	-58.2	1.4	179.2
310.000	1.3	175.6	14.21	-54.1	14.26	-54.3	1.3	175.6
330.000	1.2	171.4	15.88	-46.5	15.95	-46.6	1.2	172.1
350.000	1.1	168.0	17.38	-34.6	17.35	-34.7	1.1	168.7
370.000	1.0	164.5	18.08	-18.5	18.15	-18.5	1.1	165.3
390.000	1.0	161.1	17.76	-2.0	17.82	-2.0	1.0	162.0
410.000	1.0	157.9	16.64	10.9	16.69	10.9	1.0	158.7
430.000	1.0	154.8	15.29	19.2	15.23	19.2	1.0	155.5
450.000	1.1	151.6	13.92	24.0	13.86	24.0	1.0	152.5
470.000	1.1	149.1	12.63	25.9	12.56	26.5	1.1	149.5
490.000	1.2	146.3	11.47	27.3	11.51	27.1	1.1	146.7
510.000	1.2	143.3	10.48	27.3	10.52	27.3	1.2	143.7
530.000	1.3	140.4	9.52	27.3	9.58	26.7	1.2	140.9
550.000	1.4	137.6	8.75	26.2	8.73	26.0	1.3	138.3
570.000	1.4	134.6	8.05	25.0	8.05	24.6	1.4	135.5
590.000	1.6	132.0	7.42	23.5	7.35	23.4	1.5	133.5
610.000	1.7	129.6	6.78	21.6	6.83	21.7	1.6	130.8
630.000	1.8	127.4	6.34	20.0	6.29	19.9	1.8	128.3
650.000	1.9	124.9	5.83	18.3	5.86	18.0	1.9	125.8
670.000	2.0	121.7	5.46	16.1	5.47	15.9	2.0	123.2
690.000	2.2	118.9	5.06	13.6	5.07	13.6	2.2	120.3
710.000	2.3	116.3	4.72	11.3	4.71	11.3	2.3	117.9
730.000	2.5	113.8	4.42	8.9	4.39	8.9	2.5	115.8
750.000	2.8	111.7	4.10	6.6	4.11	6.4	2.6	113.5
770.000	3.0	110.4	3.85	4.2	3.87	4.2	2.8	111.3
790.000	3.1	108.8	3.59	1.9	3.61	2.0	3.0	109.2
810.000	3.3	106.8	3.35	-0.4	3.35	-0.3	3.2	107.0
830.000	3.4	104.7	3.12	-2.5	3.11	-2.5	3.4	104.9
850.000	3.6	102.6	2.90	-4.9	2.90	-4.8	3.6	103.1
870.000	3.7	100.3	2.68	-7.2	2.68	-7.1	3.9	101.4
890.000	3.9	98.0	2.47	-9.2	2.46	-9.2	4.1	99.5
910.000	4.2	95.8	2.28	-11.6	2.28	-11.7	4.3	97.7
930.000	4.4	94.6	2.13	-13.9	2.13	-13.9	4.5	95.8
950.000	4.7	93.2	1.98	-16.2	2.00	-16.3	4.8	93.8
970.000	4.9	91.7	1.85	-18.5	1.88	-18.5	5.0	92.1
990.000	5.1	89.6	1.76	-20.6	1.76	-20.6	5.2	90.1

Table 4

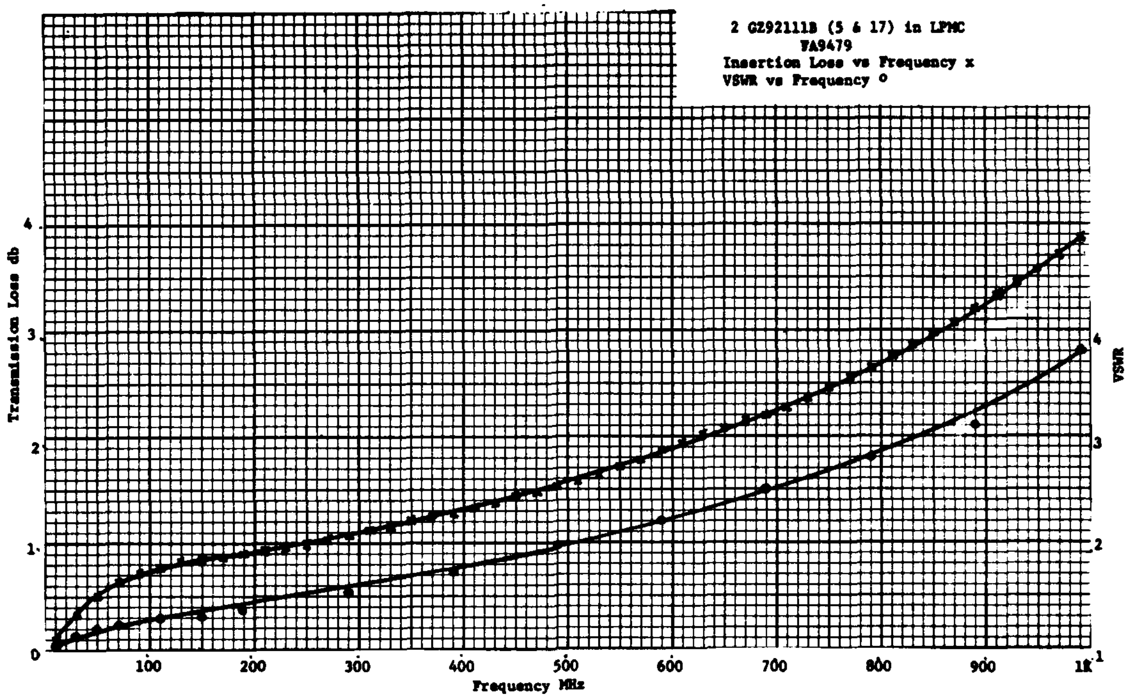


Figure 20

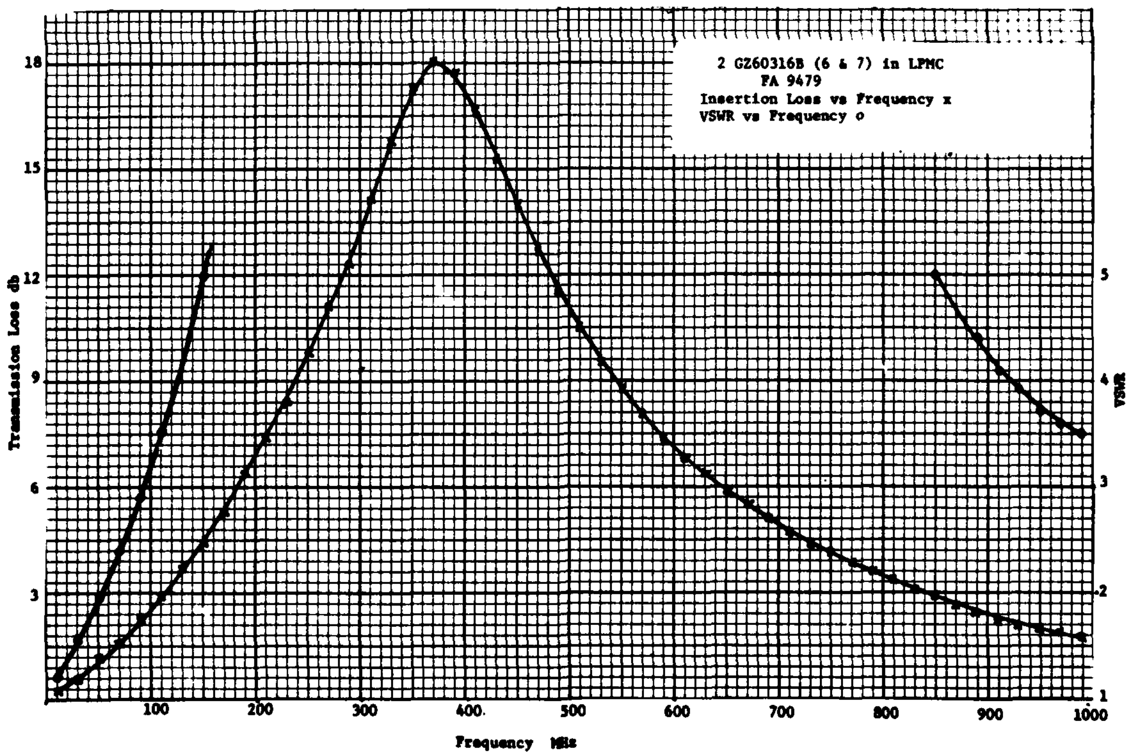


Figure 21

FREQUENCY MHZ	RETURN LOSS INPUT (S11) DB	ANG	TRANS. LOSS FORWARD (S21) DB	ANG	TRANS. LOSS REVERSE (S12) DB	ANG	RETURN LOSS OUTPUT (S22) DB	ANG
			CALIBRATION CHECK (THRU)					
10.000	47.7	-121.1	0.01	-0.0	0.01	-0.0	41.5	-112.8
30.000	49.5	-64.1	0.00	0.1	0.01	-0.0	44.6	-105.4
50.000	42.2	-76.7	0.00	0.1	0.01	-0.0	42.7	-74.9
70.000	40.2	-100.4	0.00	-0.0	0.01	-0.1	38.8	-68.9
90.000	44.5	-118.9	0.01	0.1	0.01	0.1	37.5	-75.5
110.000	48.0	-84.7	0.01	-0.0	0.00	0.1	37.9	-88.9
130.000	41.3	-81.2	0.00	-0.0	0.00	0.1	41.1	-104.5
150.000	39.1	-100.0	0.01	0.0	0.01	0.0	44.4	-114.3
170.000	41.9	-117.9	0.01	0.0	0.01	0.0	57.5	-102.1
190.000	45.5	-94.2	0.01	-0.0	0.00	-0.0	48.6	-63.7
210.000	40.2	-80.0	0.01	-0.0	0.01	-0.0	42.5	-69.8
230.000	37.9	-99.1	0.01	-0.0	0.01	0.1	38.1	-83.9
250.000	39.5	-110.4	0.01	0.1	0.02	0.0	35.3	-93.7
270.000	39.5	-92.7	0.01	0.0	0.02	0.0	33.8	-97.7
290.000	37.5	-82.1	0.02	0.0	0.02	0.0	33.1	-98.4
310.000	35.7	-87.0	0.02	-0.0	0.01	0.1	31.3	-95.0
330.000	33.2	-89.3	0.01	-0.0	0.01	-0.0	30.8	-92.4
350.000	32.8	-89.0	0.02	-0.0	0.01	-0.1	30.5	-91.1
370.000	31.5	-88.4	0.03	-0.0	0.02	-0.0	30.1	-89.5
390.000	30.5	-90.3	0.03	-0.1	0.03	-0.0	30.2	-88.9
410.000	29.6	-93.2	0.03	-0.0	0.03	-0.0	30.0	-89.4
430.000	28.9	-96.7	0.03	-0.0	0.02	-0.1	30.0	-89.3
450.000	28.8	-100.9	0.04	-0.1	0.04	-0.1	30.2	-93.8
470.000	29.6	-99.2	0.04	0.0	0.03	0.0	31.2	-97.4
490.000	29.0	-89.4	0.03	-0.1	0.03	-0.1	31.5	-98.6
510.000	27.7	-85.1	0.03	-0.6	0.02	0.1	31.5	-96.9
530.000	26.6	-87.9	0.03	-0.1	0.03	-0.1	31.2	-89.8
550.000	26.3	-88.4	0.04	-0.1	0.04	-0.0	29.3	-87.6
570.000	25.4	-89.0	0.06	-0.1	0.05	-0.7	27.8	-90.3
590.000	24.4	-93.8	0.07	-0.1	0.06	-0.1	27.0	-95.0
610.000	24.6	-103.5	0.08	0.0	0.07	0.0	27.2	-98.1
630.000	26.4	-108.1	0.07	0.2	0.08	0.1	27.2	-97.6
650.000	27.6	-96.4	0.05	0.2	0.05	0.2	27.2	-92.4
670.000	26.3	-85.1	0.05	0.2	0.05	0.0	27.3	-86.7
690.000	25.7	-85.1	0.04	0.1	0.04	-0.0	26.6	-84.4
710.000	25.6	-86.3	0.05	0.0	0.05	-0.1	26.0	-86.0
730.000	25.1	-82.5	0.05	-0.0	0.05	-0.1	26.1	-89.9
750.000	23.7	-85.1	0.05	-0.1	0.05	-0.1	26.8	-92.6
770.000	23.1	-93.4	0.06	-0.1	0.06	-0.0	27.9	-91.4
790.000	23.7	-100.7	0.05	-0.1	0.05	-0.1	27.9	-87.2
810.000	24.9	-100.4	0.05	0.0	0.05	-0.1	27.1	-82.9
830.000	24.9	-98.5	0.07	0.0	0.06	-0.1	25.9	-82.2
850.000	25.1	-100.7	0.08	-0.1	0.08	0.0	25.1	-85.1
870.000	26.0	-102.0	0.08	0.0	0.08	-0.1	24.4	-87.6
890.000	26.6	-92.9	0.06	0.0	0.06	0.0	24.2	-87.9
910.000	25.5	-84.5	0.06	-0.0	0.07	-0.0	23.6	-87.4
930.000	24.3	-85.0	0.07	-0.1	0.07	-0.1	23.3	-87.3
950.000	23.5	-88.9	0.08	-0.1	0.09	-0.2	23.0	-87.7
970.000	23.2	-92.3	0.09	-0.2	0.10	-0.3	23.0	-89.3
990.000	23.1	-95.6	0.10	-0.0	0.11	-0.1	23.4	-89.5

Table 5

2.2.2 Surge Tests

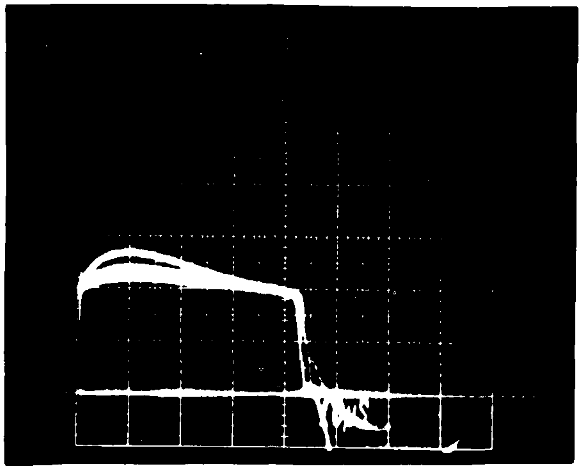
Surge tests were performed on the coaxial module in conjunction with two GZ60316B low capacity diodes mounted back to back for bipolar action. Surge source was a Keytek Model 424 Surge Generator Monitor with both 8 X 20 and 1.2 X 50 plugin units. Results were recorded on a Tektronix Model 7834 storage oscilloscope. Tests were performed at the General Semiconductor Industries plant.

Tests 1, 2 and 3 are shown pictorially in Figure 22A. All used the 8 X 20 wave shape. The circuit was not terminated. Conical spring in the holder.

a. 500 volts, 24 amperes, 11 volt clamp
b. 1000 volts, 49 amperes, 12 volt clamp. With slight spike but very little difference.
c. 1000 volts, 98 amperes. Shows bad negative excursion of approximately 10 volts. This latter probably due to heating. The device was operating beyond its limits.

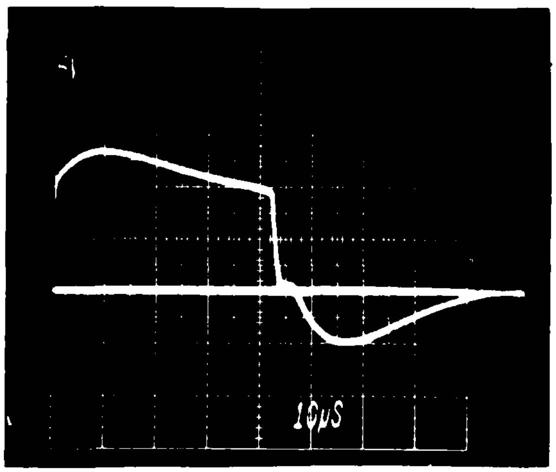
Test 4, Figure 22B is a repeat of the 1000 volt at 98 amperes using a flat non-inductive spring. The clamping voltage was lowered by approximately one volt. Note negative pulse shift.

Test 5, Figure 22C used a 1.2 X 50 wave shape, applying 1000 volts at 66 amperes. The device clamped at 12 volts with no negative excursion.

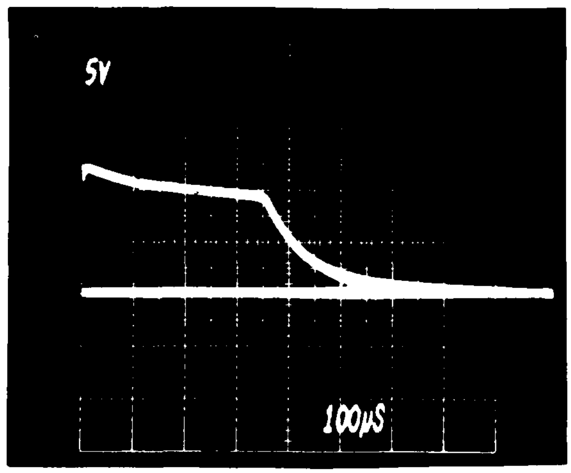


A. Test 1. 500 Volts 24 Amperes
Test 2. 1000 Volts 49 Amperes
Test 3. 1000 Volts 98 Amperes

8 x 20 Waveshape



B. Test 4. 1000 Volts 98 Amperes
(Non-inductive spring)
8 x 20 Waveshape



C. Test 5. 1000 Volts 66 Amperes
(Non-inductive spring)
1.2 x 50 Waveshape

Figure 22

Surge Tests

2GZ60316B (Bipolar Connected) in LPMC FA9479

CHAPTER 3

CONCLUSION AND RECOMMENDATIONS

1. <u>Conclusion</u>

Square wave tests on the FA9455A barrier strip type protection module, insertion loss tests on the FA9479 coaxial module and surge testing of both modules indicated that within test parameters, the modules are limited only by the characteristics and capabilities of the surge suppressor devices used. i.e., they are device limited. However, a series of tests performed by Illinois Institute of Technology, Research Institute (4) to determine effectiveness in supressing EMP did indicate a problem in handling short, nanosecond, impulses.

2. <u>Recommendations</u>

The conical spring used in both types of modules should be replaced with a "Belleville washer" type spring as described in the introduction and pictured in Figure 3. This will require minor modification of the caps for both devices.

APPENDIX A

Relationship Derivation, Transmission Loss/Return Loss

Return loss is a term used to describe the degree of mismatch introduced by a TranZorb in a coaxial line. Whereas transmission loss (or insertion loss) is defined as

$$\frac{P_{transmitted}}{P_{incident}} .$$

Return loss is defined as

$$\frac{P_{reflected}}{P_{incident}} .$$

Thus for a well matched line, the insertion loss in db would be close to zero, since the ratio of the transmitted to the incident power would be close to one. On the other hand, the return loss in db would be a large number, since the reflected power would be a small fraction of the incident power. Given the return loss, the transmission loss can be calculated.

Since $P_{incident} = P_{transmitted} + P_{reflected}$, the VSWR can be derived from the return loss as follows:

The return loss in db is defined as [5].

$$\text{Return Loss, db} = 10 \log_{10} |\Gamma|^2 \quad , \tag{1}$$

where

$$|\Gamma| = \text{magnitude of the voltage reflection coefficient.}$$

Since

$$|\Gamma| = \frac{\rho-1}{\rho+1} \quad , \tag{2}$$

where

$$\rho = \text{VSWR} \quad , \tag{3}$$

we can write (1) as

$$\text{Return Loss, db} = 20 \log_{10} \left(\frac{\rho-1}{\rho+1}\right) . \tag{4}$$

Solving for ρ

$$\rho = \frac{1 + 10^{+(\text{return loss, db})/20}}{1 - 10^{+(\text{return loss, db})/20}} \quad . \tag{5}$$

Note that the return loss is always a negative number or zero.

A similar computation can be performed to determine the VSWR from the transmission loss, using

$$\text{Transmission Loss (db)} = 10 \log (1 - |\Gamma|^2) \quad , \tag{6}$$

and solving for ρ. Care should be taken to account for the power dissipated by the device under test when using transmission loss to determine the VSWR.

APPENDIX B

REFERENCES

1. General Semiconductor Industries, Tempe, Arizona, Product Catalog 1978-1979.

2. Specification Sheets for low capacity transient suppressors. See Appendix C.

3. Fink, Donald G., Editor-in-Chief, Electronics Engineers' Handbook, First Edition, pp 9-5 and 9-6.

4. Illinois Institute of Technology, Research Institute, Report Project E6455 conducted under Task 3 of Sub-contract No. S-79-01001 with Florida Institute of Technology. Report dated May 1979.

5. Smith, Phillip H., "Electronic Applications of the Smith Chart", McGraw-Hill Book Company, New York, 1969, pp 37-38.

APPENDIX C

SPECIFICATION SHEETS

GENERAL SEMICONDUCTOR INDUSTRIES, INC.

TRANSZORB

TRANSIENT VOLTAGE SUPPRESSORS

1.5KC6.8

THRU

1.5KC110A

DESCRIPTION

This leadless TransZorb is designed for direct retro-fit or replacement of a gas-discharge suppressor when lower voltages are needed to protect voltage sensitive circuitry. For Bipolar applications, see notes on the reverse side.

The TransZorb has a peak pulse power rating of 1500 watts for 1 millisecond and therefore can be used in applications where induced lightning on rural or remote transmission lines present a hazard to the electronic circuitry. (Reference: R.E.A. Specification P.E. 60). The response time of TransZorb clamping action is effectively instantaneous (better than 1×10^{-12} sec.); therefore, they can protect Integrated Circuits, MOS devices, Hybrids and other voltage-sensitive semiconductors and components. TransZorbs can also be used in series or parallel to increase the peak power ratings.

TransZorbs have proven to be effective in Airborne Avionics and Controls, Mobil Communication Equipment, Computer Power Supplies, Numerically Controlled Machinery, and in many other applications where inductive and switching transients are present.

(Shown 2 Times Actual Size)

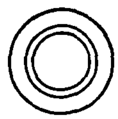
- **1500 watts peak power dissipation**
- **Available in ranges from 6.8V to 110V.**

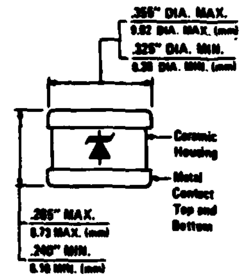
MAXIMUM RATINGS

- 1500 Watts of Peak Pulse Power dissipation at 25°C
- $t_{clamping}$ (0 volts to BV min): Less than 1×10^{-12} seconds
- Operating and Storage Temperatures: −65° to +175°C
- Forward surge rating: 200 amps, 1/120 second at 25° C
- Steady State power dissipation: 1.0 W
- Repetition rate (duty cycle): .01%

MECHANICAL CHARACTERISTICS

- Ceramic Case with Metal Caps
- Weight: 1.25 grams (approximate)
- *Polarity marked with polarity symbol*
- Body marked with Logo ⁘ and type number





(Shown 2 Times Actual Size)

ELECTRICAL CHARACTERISTICS

- Clamping Ratio: 1.33 @ Full rated power
  1.15 @ 50% rated power

Clamping Ratio: The ratio of the actual Vc (Clamping Voltage) to the actual BV (Breakdown Voltage) as measured on a specific device (See figure 3 for test pulse wave shape.)

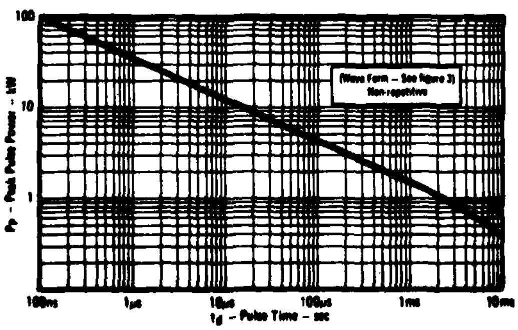


FIGURE 1 — Peak Pulse Power vs Pulse Time

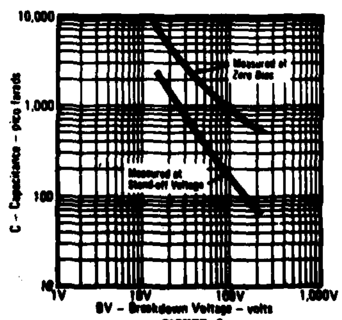


FIGURE 2
Typical Capacitance vs Breakdown Voltage

ABBREVIATIONS & SYMBOLS

V_R Stand Off Voltage. Applied Reverse Voltage to assure a nonconductive condition. (See Note 1)

BV(min) This is the *minimum Breakdown* Voltage the device will exhibit and is used to assure that conduction does not occur prior to this voltage level at 25°C.

V_C(max) Maximum Clamping Voltage. The maximum peak voltage appearing across the TransZorb when subjected to the peak pulse current in a one millisecond time interval. The peak pulse voltages are the combination of voltage rise due to both the series resistance and thermal rise.

I_{PP} Peak Pulse Current - See Figure 3

P_P Peak Pulse Power

I_R Reverse Leakage

Note 1:
A TransZorb is normally selected according to the reverse "Stand Off Voltage" (V_R) which should be equal to or greater than the DC or continuous peak operating voltage level

ELECTRICAL CHARACTERISTICS at 25°C

GENERAL SEMICONDUCTOR PART NUMBER	REVERSE STAND-OFF VOLTAGE (See Note 1) V_R VOLTS	BREAKDOWN VOLTAGE BV @ VOLTS Min. - Max.	I_T mA	MAXIMUM CLAMPING VOLTAGE @ I_{PP} (See Fig. 3) V_C VOLTS	MAXIMUM REVERSE LEAKAGE @ V_R I_R μA	MAXIMUM PEAK PULSE CURRENT (See Fig. 3) I_{PP} A	MAXIMUM TEMPERATURE COEFFICIENT OF BV %/°C
1.5KC6.8	5.50	6.12 - 7.48	10	10.8	1000	139	.057
1.5KC6.8A	5.80	6.45 - 7.14	10	10.5	1000	143	.057
1.5KC7.5	6.05	6.75 - 8.25	10	11.7	500	128	.061
1.5KC7.5A	6.40	7.13 - 7.88	10	11.3	500	132	.061
1.5KC8.2	6.63	7.38 - 9.02	10	12.5	200	120	.065
1.5KC8.2A	7.02	7.79 - 8.61	10	12.1	200	124	.065
1.5KC9.1	7.37	8.19 - 10.0	1	13.8	50	109	.068
1.5KC9.1A	7.78	8.65 - 9.55	1	13.4	50	112	.068
1.5KC10	8.10	9.00 - 11.0	1	15.0	10	100	.073
1.5KC10A	8.55	9.5 - 10.5	1	14.5	10	103	.073
1.5KC11	8.92	9.9 - 12.1	1	16.2	5	93	.075
1.5KC11A	9.40	10.5 - 11.6	1	15.6	5	96	.075
1.5KC12	9.72	10.8 - 13.2	1	17.3	5	87	.078
1.5KC12A	10.2	11.4 - 12.6	1	16.7	5	90	.078
1.5KC13	10.5	11.7 - 14.3	1	19.0	5	79	.081
1.5KC13A	11.1	12.4 - 13.7	1	18.2	5	82	.081
1.5KC15	12.1	13.5 - 16.5	1	22.0	5	68	.084
1.5KC15A	12.8	14.3 - 15.8	1	21.2	5	71	.084
1.5KC16	12.9	14.4 - 17.6	1	23.5	5	64	.086
1.5KC16A	13.6	15.2 - 16.8	1	22.5	5	67	.086
1.5KC18	14.5	16.2 - 19.8	1	26.5	5	56.5	.088
1.5KC18A	15.3	17.1 - 18.9	1	25.2	5	59.5	.088
1.5KC20	16.2	18.0 - 22.0	1	29.1	5	51.5	.090
1.5KC20A	17.1	19.0 - 21.0	1	27.7	5	54	.090
1.5KC22	17.8	19.8 - 24.2	1	31.9	5	47	.092
1.5KC22A	18.8	20.9 - 23.1	1	30.6	5	49	.092
1.5KC24	19.4	21.6 - 26.4	1	34.7	5	43	.094
1.5KC24A	20.5	22.8 - 25.2	1	33.2	5	45	.094
1.5KC27	21.8	24.3 - 29.7	1	39.1	5	38.5	.096
1.5KC27A	23.1	25.7 - 28.4	1	37.5	5	40	.096
1.5KC30	24.3	27.0 - 33.0	1	43.5	5	34.5	.097
1.5KC30A	25.6	28.5 - 31.5	1	41.4	5	36	.097
1.5KC33	26.8	29.7 - 36.3	1	47.7	5	31.5	.098
1.5KC33A	28.2	31.4 - 34.7	1	45.7	5	33	.098
1.5KC36	29.1	32.4 - 39.6	1	52.0	5	29	.099
1.5KC36A	30.8	34.2 - 37.8	1	49.9	5	30	.099
1.5KC39	31.6	35.1 - 42.9	1	56.4	5	26.5	.100
1.5KC39A	33.3	37.1 - 41.0	1	53.9	5	28	.100
1.5KC43	34.8	38.7 - 47.3	1	61.9	5	24	.101
1.5KC43A	36.8	40.9 - 45.2	1	59.3	5	25.3	.101
1.5KC47	38.1	42.3 - 51.7	1	67.8	5	22.2	.101
1.5KC47A	40.2	44.7 - 49.4	1	64.8	5	23.2	.101
1.5KC51	41.3	45.9 - 56.1	1	73.5	5	20.4	.102
1.5KC51A	43.6	48.5 - 53.6	1	70.1	5	21.4	.102
1.5KC56	45.4	50.4 - 61.6	1	80.5	5	18.6	.103
1.5KC56A	47.8	53.2 - 58.8	1	77.0	5	19.5	.103
1.5KC62	50.2	55.8 - 68.2	1	89.0	5	16.9	.104
1.5KC62A	53.0	58.9 - 65.1	1	85.0	5	17.7	.104
1.5KC68	55.1	61.2 - 74.8	1	98.0	5	15.3	.104
1.5KC68A	58.1	64.6 - 71.4	1	92.0	5	16.3	.104
1.5KC75	60.7	67.5 - 82.5	1	108.0	5	13.9	.105
1.5KC75A	64.1	71.3 - 78.8	1	103.0	5	14.6	.105
1.5KC82	66.4	73.8 - 90.2	1	118.0	5	12.7	.105
1.5KC82A	70.1	77.9 - 86.1	1	113.0	5	13.3	.105
1.5KC91	73.7	81.9 - 100.0	1	131.0	5	11.4	.106
1.5KC91A	77.8	86.5 - 95.5	1	125.0	5	12.0	.106
1.5KC100	81.0	90.0 - 110.0	1	144.0	5	10.4	.106
1.5KC100A	85.5	95.0 - 105.0	1	137.0	5	11.0	.106
1.5KC110	89.2	99.0 - 121.0	1	158.0	5	9.5	.107
1.5KC110A	94.0	105.0 - 116.0	1	152.0	5	9.9	.107

Vf at 100 AMPS PEAK, 8.3 MSEC SINE WAVE equals 3.5 VOLTS MAXIMUM

TransZorbs™ can be used in series or parallel to increase their power handling capability. No precautions are required when using TransZorbs in a series string and power dissipation for two or more devices of the same type is equally shared. When using TransZorbs in parallel it is necessary for the units to be closely matched (approx. .1 volt of each other) in order for equal sharing to take place. Matched sets can be ordered from the factory for a small additional charge.

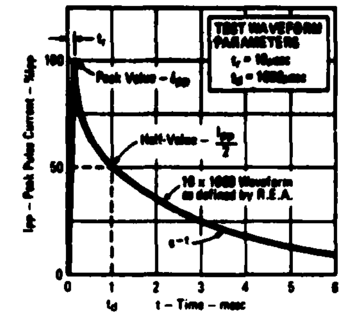


FIGURE 3 — Pulse Wave Form

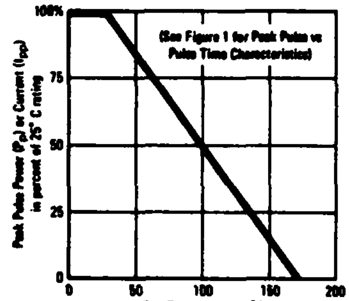


FIGURE 4 — Derating Curve

Non-standard voltage types between those tabulated may be specified as illustrated:

Family Type	Nominal BV	Tolerance Suffix
1.5KC	7.2	A

BV Will be Nominal BV ±5% for "A" suffix types and ±10% for non-suffix types at the test current of the next lower standard voltage type.

V_R Will be 85% of Nominal BV for "A" suffix type and 81% of Nominal BV for non-suffix types.

V_C Will be proportionally interpolated between the two neighboring standard types.

I_R Will be that of the next lower standard type.

I_{PP} Will be proportionately interpolated between the two neighboring standard types.

BIPOLAR APPLICATIONS

For Bipolar use C or CA Suffix for types 1.5KC7.5 through types 1.5KC110. Electrical characteristics apply in both directions.

BREAKDOWN VOLTAGE: BV @ 1 mA 34.2V Min. 37.8V Max.

REVERSE LEAKAGE CURRENT: I_R @ 31 V: 5µA Max.

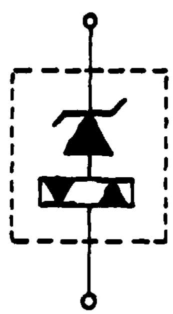
CLAMPING VOLTAGE @ 30A I_{pp}: 55V Max.

MAXIMUM PEAK PULSE CURRENT I_{pp}: 30A, 10 x 1000 µsec waveform

CAPACITANCE @ 0v Bias: 200 pf Max.

1 TransZorb Cell

2 Varistor Cells

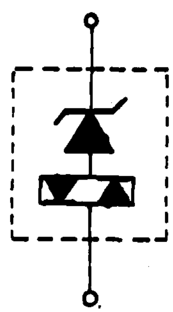


GENERAL SEMICONDUCTOR INDUSTRIES, INC. 2001 WEST TENTH PLACE • TEMPE, ARIZONA 85281	DRAWN BY J.J. Pizzicaroli
	APPROVED
	REV. ø — DATE 14 Jun 79
CUSTOMER: FLORIDA INSTITUTE OF TECHNOLOGY	
CUSTOMER PART NO:	
GSI PART NO: GZ92111A	

BREAKDOWN VOLTAGE:	1 mA, 48.5V Min. 53.6V Max.
REVERSE LEAKAGE CURRENT:	I_R @ 44V: 5 µA Max.
CLAMPING VOLTAGE @ 21A I_{pp}:	75V Max.
MAXIMUM PEAK PULSE CURRENT I_{pp}:	21A, 10 x 1000 µsec waveform
CAPACITANCE @ 0v Bias:	200 pf Max.

1 TransZorb Cell

2 Varistor Cells



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REV. Ø	DATE 14 Jun 79
CUSTOMER:	FLORIDA INSTITUTE OF TECHNOLOGY
CUSTOMER PART NO:	
GSI PART NO:	GZ92111B

ELECTRICAL CHARACTERISTICS:

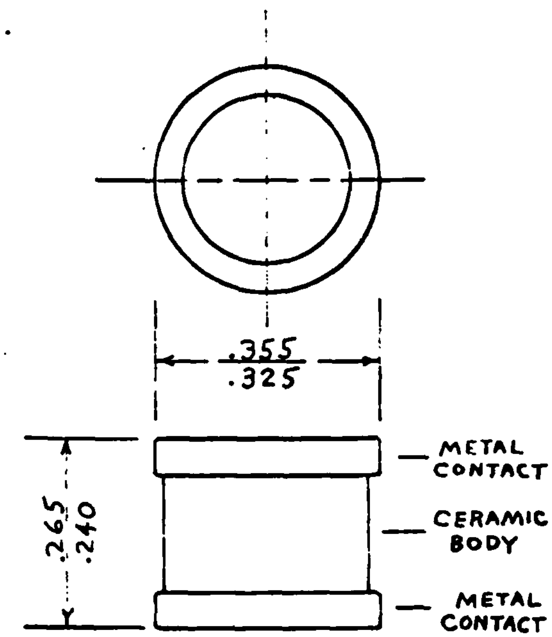
Breakdown Voltage: BV @ 10mA: 6.66V min., 8.14V max.

Reverse Leakage Current: Ir @ 5.0V: 1500µA max.

Clamping Voltage @ 70A Ipp: 12V max.

Maximum Peak Pulse Current I_{pp}:
70A down to ½ crest value in 1msec.

Capacitance @ 0V Bias: 250pf max.



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GSI PART NO: GZ60316B	